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February 2011
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LOTS OF POINTS.


NONE OF REFERENCE.
FROM EVERY ANGLE, THE CTS-V COUPE BREAKS NEW GROUND, WHILE THE BRAKE LIGHT DOUBLES AS A SPOILER TO MAKE SURE IT NEVER LEAVES IT.
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COVER
Retro Google TV logo by The Heads of State

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Explore the technologies behind the smart grid.


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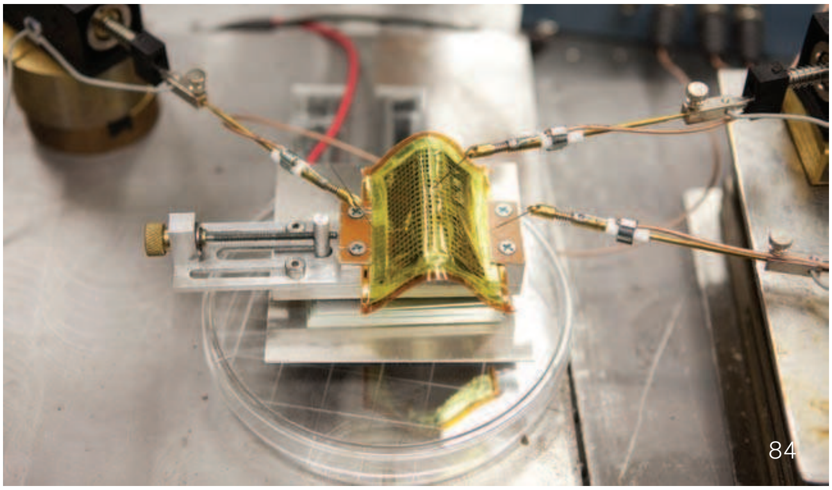
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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

DON'T DISREGARD NUCLEAR

That nuclear power is at least somewhat more expensive than fossil fuels was never in question ("Giant Holes in the Ground," November/December 2010). The question is whether we are going to do anything to move away from fossil fuels, and how nuclear power compares economically with other non-emitting options. Nuclear is stalling because current policies give it no significant advantage over fossil fuels, while renewables are being built by government mandate, essentially regardless of cost. I disagree with Matthew Wald's characterization of nuclear's loan guarantees as a significant subsidy. This support is tiny compared with the massive subsidies given to renewables. For a fraction of what the government has spent supporting renewables in just the last few years, it could provide loan guarantees for all reactors built from this day forward. In any fair competition among non-emitting sources, nuclear would do very well. Fortunately, there is a movement afoot to pass a Clean Energy Standard that includes both nuclear and renewables. Such a policy would solve all the "problems" nuclear is having right now.

James Hopf
San Jose, California

Wald's conclusion that the nuclear renaissance has failed is premature. The financial hurdles are real but not insurmountable. The renaissance requires government help in the form of loan guarantees. These are not handouts but, rather, insurance policies to cover the unforeseen. The renaissance will happen because there is simply no alternative.

Ulrich Decher
Granby, Connecticut

November/December '10

The dismissal of China as "a tiny player" in nuclear power is cavalier to say the least. The build rate for new reactors in China is beginning to approach what it was in the U.S. in the heyday of nuclear plant construction. And contrary to our experience here, China has been completing projects ahead of schedule and under budget. The agonizing in the U.S. over the future of nuclear power grows increasingly irrelevant.

Roger Arnold
Sunnyvale, California

WHAT THE WEB REALLY NEEDS

Without detracting from HTML5, I have to object to the title "The Web Is Reborn" (November/December 2010). Rather than more optimal displays of video, the Web needs an architectural solution to its nearly fatal security issues. The resources that are wasted on professional security services, firewalls, and antivirus software and its maintenance are far more than a minor inconvenience.

David Korenstein
Wayne, Pennsylvania

It seems that the Web's future is being driven by technical arguments and companies beholden to their customers. What about the public interest? The Web has emerged as the major place where the discourse necessary for democracy takes place—akin to the new radio and TV airwaves. Don't we need regulations to guarantee access and fairness?

John Fisher
New York, New York

GOOGLE VS. FACEBOOK

In "Google Misses You" (November/December 2010), Paul Boutin calls Facebook's user interface "a pain in the ass" and claims it's in conflict with 40 years of UI research. Do Google products, desktop or mobile, shine in their UIs? Google's products may be cleaner and more stable than some others', but they seem to be built by and for geeks. Designing Web and social UIs, I rarely meet people craving the Google Calendar experience or the Picasa experience.

Edo Elan
San Francisco, California

THE MEMEX

I was 13 when Vannevar Bush described the Memex in 1945, which you reflect on in "Future Perfect" (November/December 2010). The Memex, a technology that promised to give individuals access to the world's collection of information, inspired my dreams of what might be. Over the years, science and the marketplace have given us increasingly powerful computers, software, and networking.

In the eighth decade of my life I work with a company that specializes in document management software with artificial-intelligence assistants. These tools enable me to construct my own little "Memex," which holds collections totaling hundreds of thousands of documents that interest me. The cost of the devices that let me do this today is far less than would have been required to construct Bush's Memex. My computer and scanner total ten pounds, less than Bush's vision of a bulky device.

My Memex operates at speeds that would have delighted Bush, but we are still in early stages of what could be done. The author is correct in stating that looking back at the present from the perspective of 77 years in the future would probably elicit pity for the primitive state in which we live and work today.

William DeVille
Nashville, Indiana

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MARK OSTOW

A Decade of Genomics

On the 10th anniversary of the Human Genome Project, we ask: where are the therapies?

The Human Genome Project, whose results were announced in June of 2000 and published in full 10 years ago, took 13 years and $3 billion to complete. For biology, it was unprecedented in scale: it determined the sequence of three billion units, or base pairs, of human DNA. What life scientists wanted from the project was equally ambitious: they hoped sequencing our DNA would reveal the genetic causes of disease and lead to diagnoses, treatments, and cures for intractable illnesses like many forms of cancer.

In this issue of *Technology Review,* we explore what happened to those hopes.

Over the last 10 years, many advances in genomics have been made. As Jon Cohen explains in the introduction to our package of stories on the topic, which begins on page 40, "The price of sequencing DNA has dropped … to mere thousands [of dollars per person]. The number of single-gene aberrations known to cause disease … has jumped from 100 to nearly 3,000. The growing list of common diseases that have been traced to multiple genetic variants includes everything from types of blindness to autoimmune diseases and metabolic disorders like diabetes. Studies have linked more than 200 genes to cancer."

But taken as a whole, it was a long, hard decade for genomics. Researchers and clinicians will disagree about how quickly they imagined the Human Genome Project would bear fruit, but no one will contest that the genome has turned out to be bafflingly complex and that genomic information has yielded few new cures. Cohen describes some of the difficulties in his introduction, and Stephen Hall provides more detail in "The Genome's Dark Matter," beginning on page 52: "Large-scale genomic studies … have mainly failed to turn up common genes that play a major role in complex human maladies. More than three dozen specific genetic variants have been associated with type 2 diabetes … but together they have been found to explain about 10 percent of the disease's heritability … Results have been similar for heart disease, schizophrenia, high blood pressure, and other common maladies."

In short, we have expended enormous energy on searching for disease genes, but it has become clearer that a variety of other factors, once thought minor, are in fact as important to our health as genes themselves. These include how much or how little of a protein is produced (gene expression); the degree to which gene expression can be influenced by mechanisms other than changes in the underlying DNA sequence (dubbed "epigenetics," because the field studies mechanisms above—"epi"—the genome); and whether we have extra or missing copies of genes (copy-number variation).

This "missing heritability" problem—the fact that individual genes cannot account for much of a disease's heritability—has significant implications for medicine. It turns out (as Hall explains) that "a person's susceptibility to disease may depend more on the combined effect of all the genes in the background than on the disease genes in the foreground." Therefore, mapping this complex nest of genetic relationships offers the best hope for turning genomics into therapies or cures.

Consider cancer. In "Cancer's Genome," starting on page 46, Emily Singer, *Technology Review's* biomedicine editor, describes how research has proved that cancer genomics are "even more complicated than scientists had supposed." We now understand that five to as many as 20 mutations are needed to trigger cancer's cellular proliferation. But cheaper, faster sequencing technologies may, in the not-too-distant future, make personalized cancer medicine a real possibility. Singer reports on Foundation Medicine in Cambridge, Massachusetts, which wants to create clinical tests that reveal which mutations have caused a patient's particular cancer, how severe that cancer is, and what drugs will affect it. According to Singer, early results from Foundation "suggest that about half the patient tissue samples analyzed would yield plausibly 'usable' information, meaning that the analysis might suggest a particular class of drugs or better define the type of cancer." If readers are looking for hope that genomics can lead to cures for intractable diseases, companies like this are appropriate inspiration.

In Cohen's introduction, Eric Lander, who was one of the leaders of the Human Genome Project and now directs the Broad Institute (and who is also a founder of Foundation Medicine), says we should not be surprised that the genome is so complicated. He counsels a historically informed patience as we work on new genomic medicines: after all, 60 years passed between the development of germ theory and the creation of antibiotics. Genomics is harder. Lander asks, "How simple did you think it would be?"

Write and tell me what you think at jason.pontin@technologyreview.com —*Jason Pontin*

notebooks

MEDIA

Watching Viewers

Making television smarter requires understanding why it is our favorite gadget, Genevieve Bell and Brian David Johnson argue.

Do you want a Web browser on your TV? If history is any indication, your answer is probably a resounding no. We don't blame you.

In the past few decades, the technology industry has labored under the delusion that consumers would love their TV sets to behave like computers. Many tombstones now stand in place of devices built by very smart people, with incredibly smart technology inside, that made no impact. Our own company, Intel, had multiple failed attempts.

Even today, with more consumer electronics to choose from than ever before, the TV remains the most-used electronic device in the home. It is often at the center of our living rooms and bedrooms. It is where we go to relax and to gather with friends and family. For many, watching TV defines being at home.

In 2005, our group at Intel took a fresh approach. Instead of trying to build a television with PC-like features, we asked people how their TV experience could be improved. Instead of starting with assumptions about how TV had to change, we began by finding out what people loved about it.

Our ethnographers visited India, Japan, the U.K., and the United States, sometimes watching people watch TV, sometimes watching with them. We wanted to understand how people lived with their TVs and the other people around them. The results directly informed the design of the processors at the heart of new devices like those running Google's TV software and D-link's Boxee Box *(see "Searching for the Future of Television," p. 32).*

The first thing we learned was that people love TV just as it is. They love their shows and they love its simplicity. TV is always there and doesn't ask too much of them. A story they care about is always just one button away. When we asked people what they would want from a TV with computing power, they didn't talk about computing. They talked about TV. Their top three answers were that they want access to their regular broadcast TV, want access to broadcasts they have missed, and want to know what shows their friends recommend.

Delivering on all three requests does require computing. Giving viewers the shows they missed takes a combination of DVR and Web services. Telling them what friends enjoy is a mix of social networking and automatic recommendations. But it doesn't require building a TV that behaves and feels like a computer. Recognizing that, using social science to inform computer science, has given us a new generation of smart TV devices like nothing that has come before. Let's hope they fare better than their predecessors.

GENEVIEVE BELL IS DIRECTOR OF INTERACTION AND EXPERIENCE RESEARCH AT INTEL; BRIAN DAVID JOHNSON IS A FUTURIST AND DIRECTOR OF FUTURE CASTING.

ENERGY

Electric Dreams

Success for vehicles with a plug, not a gas cap, rests on more than technology, says Dan Sperling.

The history of alternative transportation fuels is a history of failure. It is a story of one fuel du jour after another—a frustrating cycle of media and political hype followed by disillusionment and abandonment.

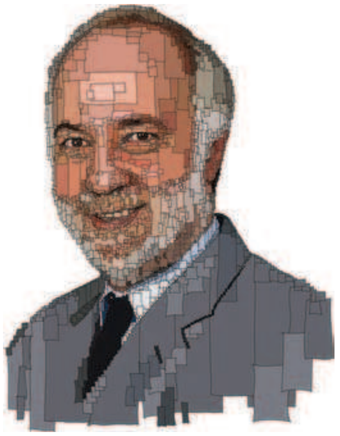
The cycle is all too familiar, from synfuels in the late 1970s to methanol in the '80s, and then electric vehicles, hydrogen, and ethanol. Only corn ethanol has survived in the United States, but it would be a stretch to call it a success, given its big carbon footprint and relatively high cost (subsidized at about $6 billion per year in the United States today). A new wave of electric vehicles are now at risk of entering the cycle again.

Replacing petroleum will be difficult and slow. Its hegemony creates huge barriers for new fuels, in terms of economics, legal liability, public skepticism, and media sensationalism. Our three best hopes—hydrogen, electricity, and biofuels—all face large challenges.

Hydrogen would require us to transform our fuel supply system. Electricity must overcome the shortcomings of batteries *(see "Will Electric Vehicles Finally Succeed?" p. 58)*. Advanced biofuels need a lot of land and leave a large carbon footprint. However, no other green energy technologies will come into being easily or quickly. At least one of these three—and probably all—must eventually thrive if we are to change the kind of energy we use for transportation.

For plug-in hybrid and all-electric vehicles, I see two possible scenarios. The most likely, judging by failed fuels of the past and recent experiences with hybrid cars like the Prius, is slow investment. After 10 years in the U.S. market-

NICK REDDYHOFF



place—13 in Japan—hybrids have gained only 3 percent of the country's market for new cars. Plug-in electric vehicles are more costly, require large-scale investment in recharging infrastructure, and are more alien to consumers. Absent any dramatic change to market conditions, can we really hope they will be more popular than hybrids?

A more optimistic scenario would require strong national standards for new vehicles, similar to regulations now being contemplated by California and the U.S. Environmental Protection Agency. The EPA already requires 40 percent reductions in fuel consumption and greenhouse-gas emissions by 2016, and it is considering further mandatory decreases of up to 6 percent per year from 2017 to 2025. Automakers could meet such standards at first with better conventional engines and gas hybrids. But they would later be forced to invest in advanced plug-in technologies, to achieve the steep improvement needed to keep pace.

This optimistic scenario is supported by the existence of large federal and state subsidies for plug-in electric vehicles, and by a strengthening commitment to them in China. While battery technology will always be expensive, the right combination of strong policy, strong competition, and consumer enthusiasm could speed the adoption of these cars.

DAN SPERLING IS DIRECTOR OF THE INSTITUTE OF TRANSPORTATION STUDIES AT THE UNIVERSITY OF CALIFORNIA, DAVIS, AND AUTHOR OF THE BOOK *TWO BILLION CARS.*

GENOMICS

Disease Decoded

Sequencing the human genome has profoundly changed our understanding of biology and disease, writes David Altshuler.

When I was in school at MIT and Harvard in the 1980s and 1990s, I was taught that there were 100,000 or so human genes, every one encoding a protein. The properties of those genes were unknown. Today, I teach that our genome contains only 21,000 protein-coding genes. To our surprise, there are thousands of additional genes that don't encode proteins. All of these genes have been described in great detail.

I was taught that the parts of the genome not encoding proteins were "junk." Today, we know that this junk makes up three-quarters of our functional DNA. Parts of it help exquisitely control where and when genes are active in the body.

I was taught that "genetic diseases," such as cystic fibrosis, are caused by mutation of a single gene, with only a small handful of these mutations known. Today, precise causes are known for 2,800 of these rare single-gene disorders.

I was taught nothing about the more complex genetics of common diseases. Today, we are learning at dizzying speed about the interplay of genes and environment in diabetes, heart disease, and other common conditions. In the past three years alone more than 1,000 genetic risk factors have been found (an increase of perhaps 50-fold), contributing to more than 100 common diseases.

Such advances would have come far later, if at all, without the Human Genome Project *(see "The Human Genome, a Decade Later," p. 40)*. But a body of knowledge is not its only legacy. It also changed the way biological research is performed.

I was trained to view scientific data as the private property of each investigator. Human genetics research groups were locked in a "race" to discover each disease gene, and there were winners and losers. This often led to fragmentation of effort and yielded results irreproducible by others. Data was collected by hand and stored in paper notebooks.

The Human Genome Project held the revolutionary view that data collected should be freely available to all. Today this view prevails in genomics and many other fields of biology and medicine. Data is shared online by scientists the world over.

Today, thanks in no small part to the genome project's example, investigators working on the same disease often publish together. Combining clinical and genetic data this way increases the statistical robustness of the claimed findings and makes for highly reproducible results.

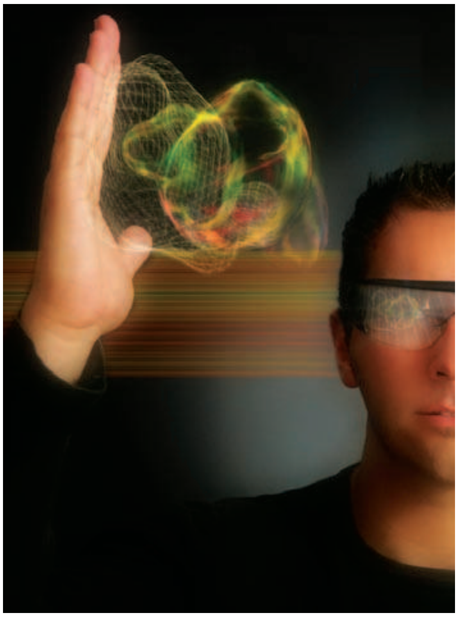
Of course, knowledge of the human genome alone is not sufficient to cure disease. It will always be the case that creativity, hard work, and good fortune are needed to translate biological data into medical progress. But without the information, understanding, and cultural changes brought on by the genome project, the benefits to patients would be much further off.

DAVID ALTSHULER IS A FOUNDING MEMBER, THE DEPUTY DIRECTOR, AND THE CHIEF ACADEMIC OFFICER OF THE BROAD INSTITUTE OF HARVARD AND MIT, AND PROFESSOR OF GENETICS AND OF MEDICINE AT HARVARD MEDICAL SCHOOL.

Augmented Reality in the Real World

Point the camera of a tablet computer or phone at a landmark, and watch as information about the building appears on the screen. Bat at bugs on a table to rehabilitate arm and shoulder movement: the bugs actually appear only on a head-mounted display.

Augmented reality programs are rapidly being adopted in a wide variety of sectors, from military and civilian training programs to online product marketing to museum exhibits. The market intelligence firm ABI Research estimates that revenue associated with augmented reality–for handheld devices alone–will have increased from $6 million in 2008 to more than $350 million by 2014.



Drivers Ed for the Military

In the past, military drivers often had to travel to learn to operate complicated, hefty vehicles—such as the armored Stryker or the mine-protected Buffalo—on large immovable simulators. Those massive systems, complete with augmented reality tools, helped drivers feel as if they were moving genuine tank and truck controls and operating the machinery. Today, researchers at the international company SAIC, working at their Orlando office, have reengineered the architecture of the system from the ground up, so that entire virtual systems, complete with the appropriate hardware to create the necessary effects, can be shrunk down to fit into one trailer. These systems can also easily be reconfigured for different vehicles.

"We've taken the entire system and made it mobile," says David Rees, senior vice president. "We've already built 13 or 14 trailers for the Army, and they can now take those trailers to wherever the troops are located."

The vehicles have external arms that can be manipulated to clear explosive devices; the virtual trainer has a system just like it that the drivers can operate, then view the results on its monitors.

Commerce and Entertainment

Stephen Barker, founder and president of Sarasota-based Digital Frontiers Media, has received national attention for the company's eye-catching interactive websites. He notes that advances in cameras and computer speeds and smart phones have dramatically enlarged the possibilities for augmented experiences. Barker describes a scenario where "for fashion, you'll want to know what a particular piece of clothing will look like. So you'll stand in front of the webcam and interact with the camera, change the clothing that you're checking out, so you can get a feeling of what it will look like on you."

At ESPN's Innovation Lab, in Orlando, Florida, the engineers have developed virtual team members for many different sports. The on-air sportscaster appears to interact with the computer-generated athletes, striding among them as they execute a variety of plays. This system was used during the 2010 World Cup, allowing analysts to break down and explain plays and formations in a virtual environment.

Museums Spring to Life

E2I Creative Studio, a lab that bridges the academic and commercial worlds, has brought a new sense of reality to Florida museum exhibits. At the Orlando Science Center, the bones of prehistoric sea creatures were failing to captivate visitors. So researchers at the University of Central Florida's Media Convergence Lab (the precursor of E2I) created a portal that resembled a science fiction time-travel device. Visitors stepped up to the portal and through it viewed an exhibit that had suddenly been "flooded" with water, bringing the bones to life. Virtual creatures slithered through the water and peered out from behind the real museum's support pillars.

E2I Creative is now developing a series of exhibits for the Fort Lauderdale Museum of Discovery and Science, including an augmented otter habitat display. Says Eileen Smith, the lab's director, "We decided to go with stylized virtual creatures, instead of attempting to make them look exactly like the real thing." The point, she continues, is to offer just enough verisimilitude to let the user's imagination take over.

Download the *Augmented Reality in the Real World white paper* to learn more about

- augmented reality games for rehabilitation;
- new tools for movie-making; and
- military training.

to market

SONY

WEB

Search Screen

THE FIRST high-definition set to have Google TV software built in, the Sony Internet TV lets viewers search for content on both television channels and the Internet *(see "Searching for the Future of Television," p. 32)*. It also provides a platform for third-party Android-based applications. The downside is a monster of a remote control, with 80 buttons.

Product: Sony Internet TV **Cost:** $600 to $1,400 **Availability:** Now
Source: www.sonystyle.com **Companies:** Google, Sony

BIOMEDICINE

Medical Machines

Assistive robots help patients out of wheelchairs and aid doctors in surgery.

Stand Alone

UNLIKE OTHER exoskeletons, this one doesn't require crutches or a backpack; two giant legs support and lift the user, who controls the system with joysticks. While bulkier than the other systems, it allows wearers to ascend steps and ramps.

Product: Rex **Cost:** $150,000 **Availability:** Now **Source:** rexbionics.com **Company:** Rex Bionics

Fancy Footwork

THIS PROSTHETIC actively senses the wearer's position and uses a motorized spring to imitate how the ankle, calf muscle, and Achilles tendon work to push off the ground. The result is a more natural gait and less pressure on the hips and back.

Product: PowerFoot BiOM **Cost:** Not available **Availability:** Now **Source:** www.iwalk.com **Company:** iWalk

Torso Control

REWALK features stabilizing crutches, motorized gears that move the legs, and a computer-equipped backpack holding a battery that powers the device for three to four hours. Motion sensors and onboard processing monitor the wearer's upper-body movements and center of gravity; when the person shifts his or her torso, the device steps appropriately.

Product: ReWalk-I **Cost:** $130,000 **Availability:** Early 2011 **Source:** www.argomedtec.com **Company:** Argo Medical Technologies

COURTESY OF IWALK, REX BIONICS, ARGO

Surgical Precision

DURING joint replacement surgery, the patient's bones have to be sculpted so that the implant can be fitted securely. This robotic surgical device uses tracking arms to monitor the position of the patient's bone and track the tip of the rotating burr being used to shave material away. It will restrain the burr if the surgeon attempts to remove bone from the wrong location.

Product: Acrobot Sculptor and Navigator **Cost:** Not available **Availability:** 2011 **Source:** www.acrobot.co.uk **Company:** Stanmore Implants

Sensitive Soles

ATTACHED with clips and Velcro straps, these motorized leg supports and foot sensors enable paraplegics to move themselves between sitting and standing positions, walk in a straight line, and turn. Crutches help stabilize the walker. Sensors in the foot pads tell the supports how to flex the knees in a natural manner, allowing wearers to move over mixed terrain. The system draws power from batteries carried in a backpack.

Product: eLegs **Cost:** $100,000 **Availability:** Mid-2011 **Source:** berkeleybionics.com **Company:** Berkeley Bionics

COURTESY OF ACROBOT, BERKELEY BIONICS

COMPUTING

Digital Dashboard

FORD HAS developed a new interface for drivers. Two LCD screens on either side of the speedometer can show a range of information, selected using two game-pad-style thumb controllers on the steering wheel. The screens can display, for example, fuel level, distance traveled, engine temperature, or the presence of another car in the vehicle's blind spot.

Product: MyFord Touch dashboard **Cost:** $1,000 as an option **Availability:** Now **Source:** www.ford.com **Company:** Ford Motor

COMPUTING

Transform Your Car

THE AUTOBOT can be retrofitted into most cars made since 1996, allowing you to remotely tap into your vehicle's engine diagnostics port and get information about issues such as cylinder misfires or fuel pressure. The device uses a 3G connection to transmit data; the information can be accessed through a website or a smart-phone app. If you need directions to your parking spot or your car is stolen, a built-in GPS will provide the car's location. And if you get into an accident, the AutoBot can send text messages to emergency services.

Product: AutoBot **Cost:** Under $300 **Availability:** Mid-2011 **Source:** www.mavizontech.com **Company:** Mavizon Technologies

COURTESY OF FORD MOTOR; MAVIZON TECHNOLOGIES

COMMUNICATIONS

Peer-to-Peer Radio

THIS DIGITAL RADIO supports a new wrinkle in Wi-Fi. Wi-Fi Direct, as it's called, lets devices such as printers, laptops, and televisions discover and communicate with each other without having to first connect to a Wi-Fi base station. For example, the technology could allow a business visitor to use a printer in the office without being given access to the corporate network.

Product: Centrino Advanced-N 6000 **Cost:** Not available **Availability:** Now **Source:** www.intel.com **Company:** Intel

BIOMEDICINE

Pocket Scanner

USING A smart-phone touch screen to display results, this portable ultrasound system is designed to provide cheap diagnostics in remote areas. With training, nonexpert field workers can use the device to take ultrasounds; images can be transmitted to off-site doctors for analysis.

Product: Smart Phone Ultrasound Imager
Cost: $5,000 to $10,000
Availability: Mid-2011, subject to FDA approval
Source: www.mobisante.com **Company:** Mobisante

WEB

Social Animals

NOW EVERYONE on the Internet will know if you're a dog. Intended for owners looking for a connection with their pet when they can't be together, the Puppy Tweets device is attached to a dog's collar and sends a signal to the owner's computer, which then updates to Twitter throughout the day. Posts consist of preworded messages based on how active the dog is and whether or not it has been barking.

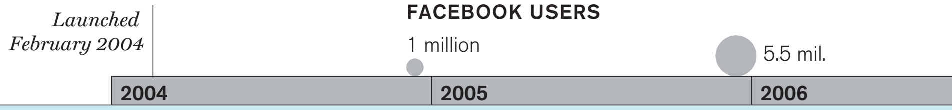
Product: Puppy Tweets **Cost:** $25 **Availability:** Now **Source:** puppytweet.com **Company:** Mattel

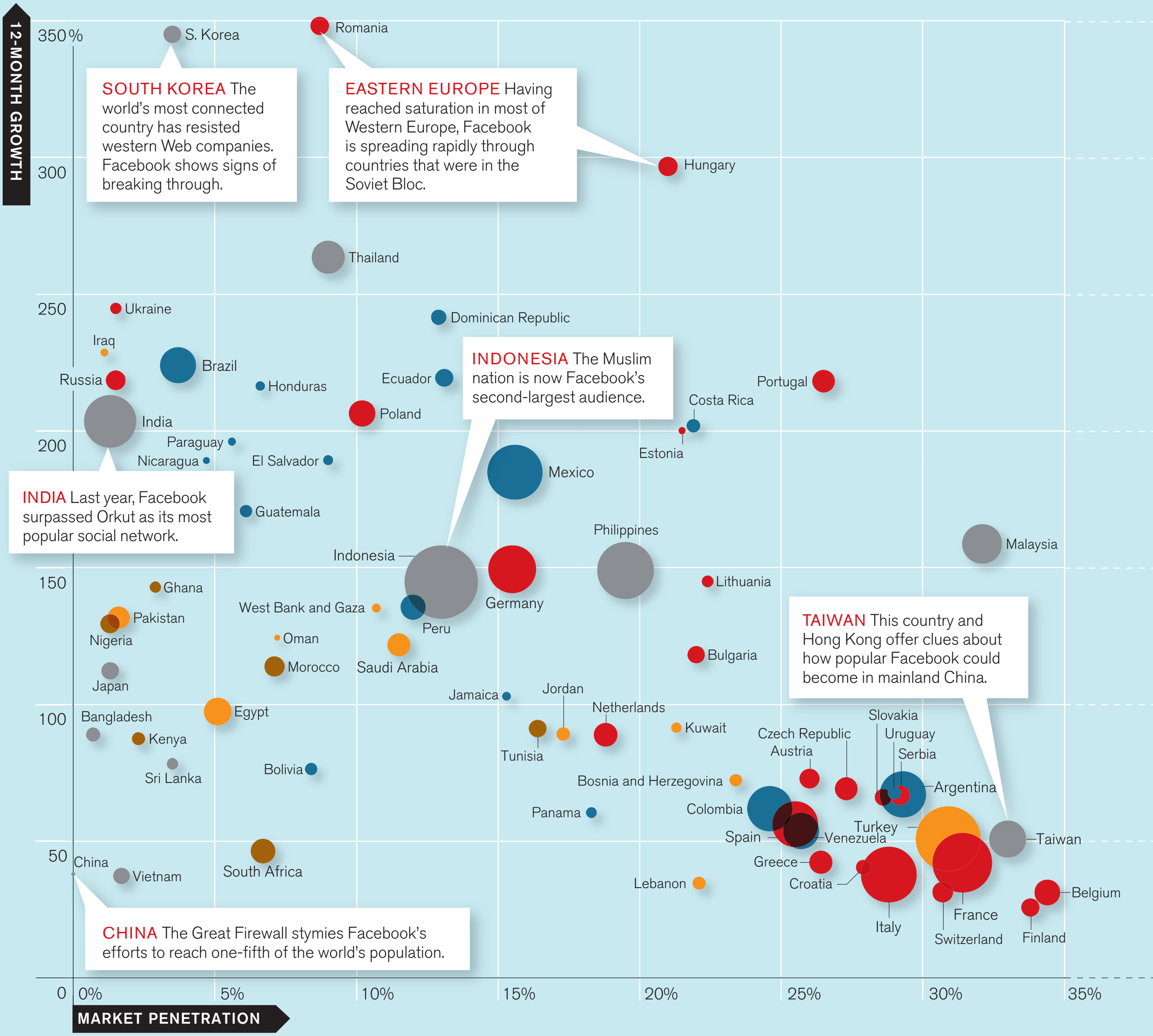
COURTESY OF INTEL; MOBISANTE; MATTEL

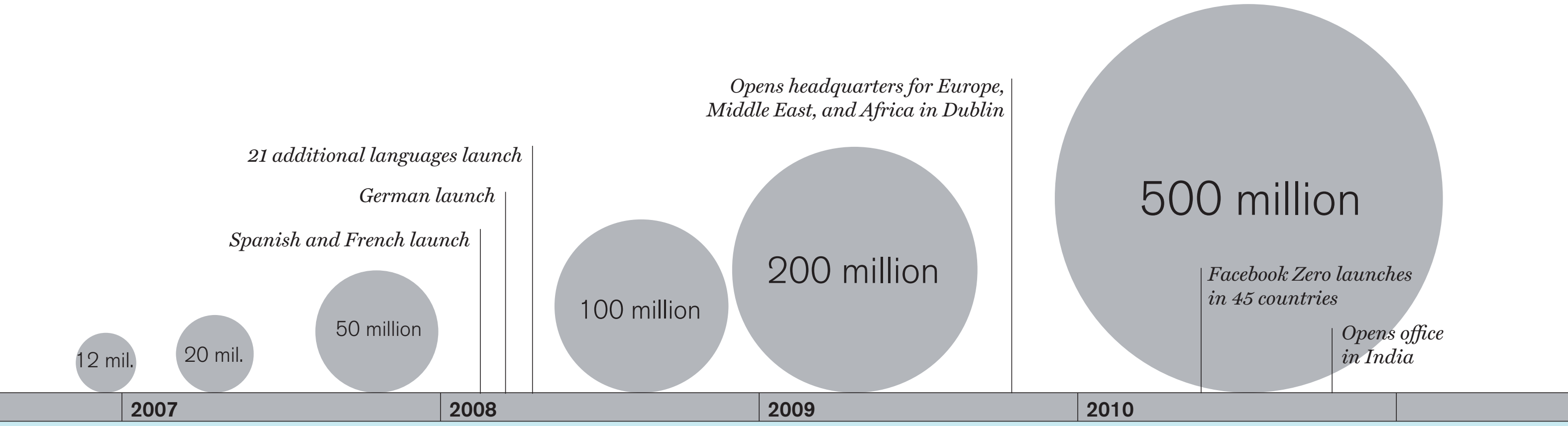
graphiti

THE ROAD TO HALF A BILLION

Over the past two years, Facebook has been solidifying its international presence. It has crowdsourced the translation of its site into dozens of languages, opened new offices abroad, and launched Facebook Zero, a stripped-down version aimed at countries where people are more likely to connect using a cell phone than a PC.







Making Friends

Facebook still has lots of room to grow.

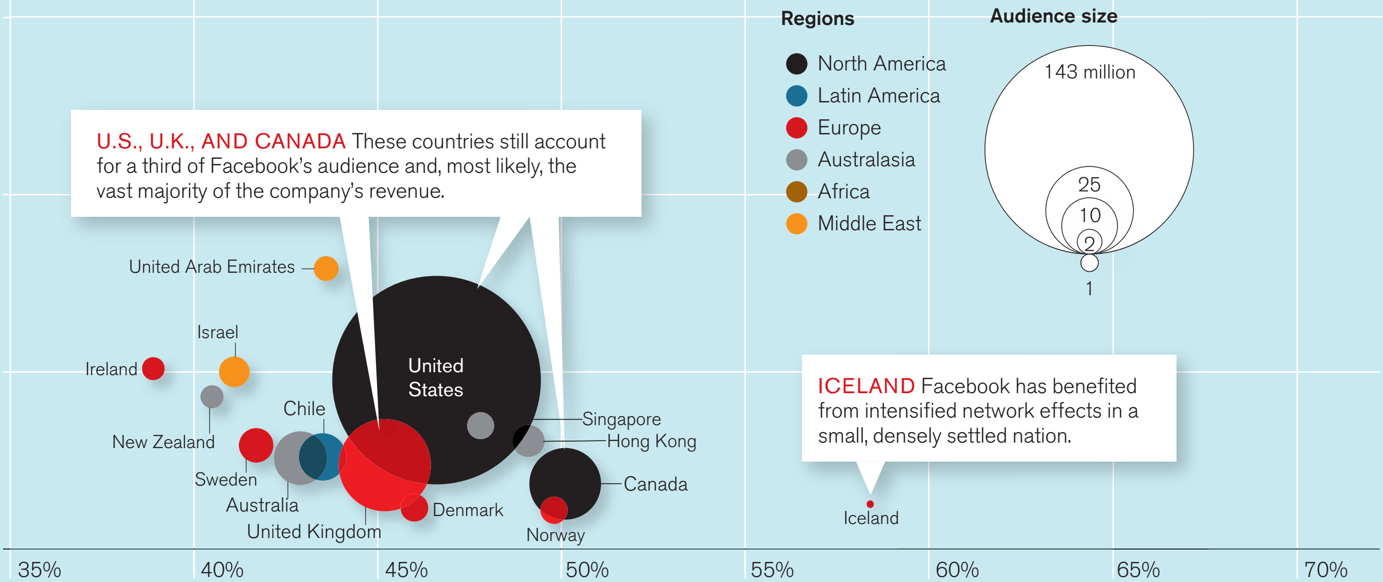
With three-quarters of its 500 million users outside the United States, Facebook has spread to every corner of the globe. But there are still plenty of people who have yet to be lured into the social network—and could be soon. As this graph shows, Facebook is only just beginning to ripple through the populations of such large countries as India and Brazil. It is also still a minor player in Japan and South Korea. And it is banned in China, the biggest Web market of all.

For most of its first six years, Facebook was largely able to sit back and let its audience expand naturally, thanks to the power of the network effect. But it now has to work harder to establish a presence in markets like Japan and South Korea, which—partly because those countries already have successful homegrown Web services—have been hard for western companies to crack.

However, one success story suggests that the company can do well in East Asia. In Taiwan, which also has a well-established Web ecosystem and is similar to Japan and South Korea in terms of broadband connectivity and technical literacy, nearly a third of all residents and half of all Internet users have a Facebook account. One factor in the growth has been a ready supply of social games for Taiwanese to play on Facebook. Such games are often created by developers in mainland China, even though the government prevents most of their countrymen from playing them. —*Matt Mahoney*

Information graphic by
TOMMY McCALL and MATT MAHONEY

Sources: Audience data is from Inside Network's Facebook Global Monitor report for November 2010; 2009 population data from the World Bank was used to calculate market penetration.



Q&A

Paul Sagan

The CEO of a company that plays a crucial role in delivering Web traffic tells us not to worry about the Internet's capacity.

You could be excused for doubting that the Internet can keep up with the rapidly increasing demands on it. In addition to all the e-mails, songs, Skype calls, and Web pages flitting about, the amount of video online is mushrooming. By 2014, video will account for roughly half of consumer Internet traffic, up from just 12 percent in 2006, according to Cisco Systems. If the Internet's ability to handle all that traffic can't keep scaling, the resulting congestion will slow all kinds of applications for everyone.

But Paul Sagan, CEO of Akamai Technologies, says that people underestimate how much capacity there is. He's in a position to know, because Akamai ushers along 15 to 30 percent of Web traffic. The company, which was founded by an MIT mathematician and graduate students in 1998, has ingenious methods for speeding the delivery of Web content. One such trick is to make sure popular pieces of content don't get trapped in bottlenecks; Akamai's technology makes highly sought files available from 75,000 servers it has stashed inside the networks of Internet service providers. From there, the files have an easier time going the "last mile" to end users. Sagan described his view of the Internet's future to *Technology Review*'s deputy editor, Brian Bergstein.

_TR_: What's a good way to describe just how much Internet traffic has exploded?

Sagan: This year, in one week we delivered as much data as we did in all of 2005.

Why do you think there's still room for so much more?

If you think of the capacity as the sum of the last miles, rather than wherever the narrowest point is at any given time, capacity is much greater. If you said, "I'm going to use one data center to deliver [online video streams of] the World Cup"—several terabits a second of simultaneous traffic for over a million users—you simply can't get that much capacity out the door, let alone through all the networks that make up the Internet, to the edges. We were able to do it because we were delivering it from the edges, where people connect to.

You're making copies of videos and other Web content and distributing them from strategic points, on the fly.

Or routes that are picked on the fly, to route around problematic conditions in real time. You could use Boston [as an analogy]. How do you want to cross the Charles to, say, go to Fenway from Cambridge? There are a lot of bridges you can take. The Internet protocol, though, would probably always tell you to take the Mass. Ave. bridge, or the BU Bridge, which is under construction right now and is the wrong answer. But it would just keep trying. The Internet can't ever figure that out—it doesn't. And we do.

But there must be an increase in demand that the architecture couldn't handle.

Sure.

Couldn't that be caused by millions of hours of high-definition video?

I think what would happen, if it gets ahead of itself, is that people would have a less than good experience, and they'd stop watching some of it, and it would drop down, and the buildout would catch up. People are putting huge investments in data center capacity. And they're putting huge investments in the last-mile networks. Why? There's huge money to be made in both. If you're in the middle, there's not a lot of money to be made, and so as we've seen Internet traffic skyrocket for 15 years, the middle always lags what's going on at the first and the last mile, and that's not going to change. [But] our view is, if you can skip the middle, the Internet will continue to scale along.

We've heard dire claims about the state of the Internet for a long time.

Predictions that the Internet is going to crash are not new. They've been around as long as we've been here, and even back to dial-up. And there are many good business opportunities that people have found by investing to make sure that that doesn't happen. And I think it's going to continue to happen. I don't think the Internet is just going to crash and burn because there's too much video.

And it's not all or nothing with video, right? Services like yours can adjust the quality of a video stream to make it take up less bandwidth if needed.

People in fact have that experience today and they don't even know. They're watching on a big screen, the bandwidth is varying a little bit in the background, and we're delivering an uninterrupted picture. There's almost the equivalent of a power brownout in the background, but it's not affecting their experience.

Isn't the problem of getting bits across the last mile much thornier for wireless?

There is a challenge in wireless, which is: as new as that infrastructure is, it was built for voice, not for data. These networks don't even speak IP as the protocol of the tower. So they're taking Internet traffic and then converting it to proprietary protocols. That's changing with 4G and probably what will follow that. And as that happens, it gets easier for Akamai to extend farther. There will be new things we'll do in wireless over the next five years. tr

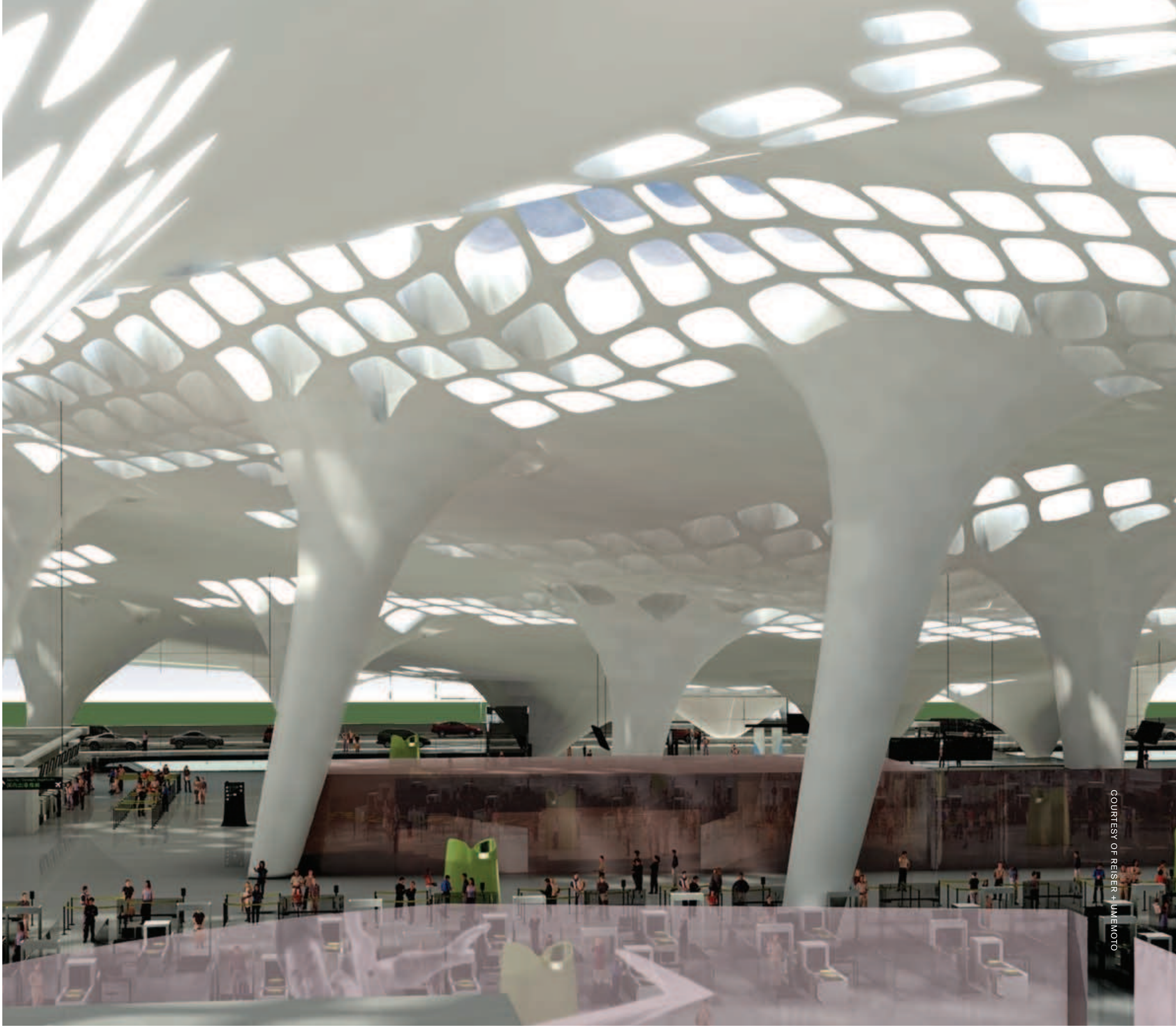
Photograph by PORTER GIFFORD

PHOTO ESSAY

Rebuilding Architecture

In the early 1990s, architects began using "parametric" software, which defines the relationships between different aspects of a design and can maintain these relationships as the aspects change. Increase the curve of a wall or adjust the area of a floor and the software will automatically draw a whole new set of plans. Now, architects use these programs to learn instantly how changes in design will affect energy use or building costs. Some let the software lead the design, making possible previously unbuildable forms.

By KATHERINE BOURZAC



COURTESY OF REISER + UMEMOTO

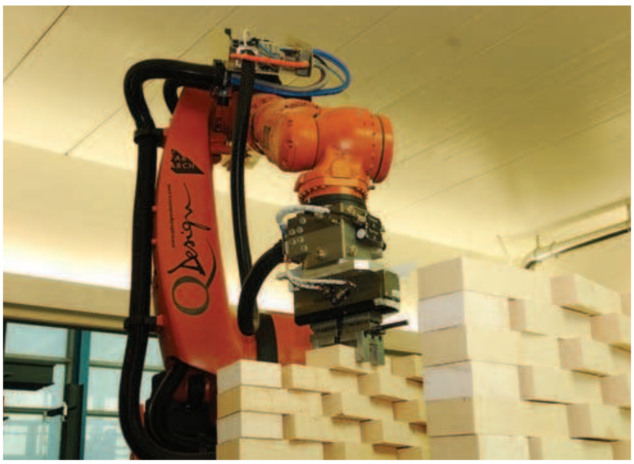
New York firm Reiser + Umemoto's proposed design for the Shenzen Airport, in China's Guangdong province, incorporates a twisted grid of skylights. The firm didn't win the bid for the airport, but the 2007 design, shown here in a digital rendering, has been influential. The firm used parametric software to calculate angles that would provide pleasant indirect natural light but wouldn't let in enough sun to raise air-conditioning bills. Producing curved concrete forms as intricate as these would be impossible without the new software.

RICHARD WAITE/ARCAID/CORBIS(SERPENTINE); JEFF TITCOMB / ALAMY (STATA)

Frank Gehry, whose firm designed the 2004 Stata Center at MIT (above), was an early pioneer in software that went beyond conventional computer-aided design (CAD). Unlike earlier CAD programs, parametric design programs calculate changes to the entire structure necessitated by, for example, changing the slope of a wall. Architects are now using software not just to help realize designs they have in mind but to create new ideas. The pattern of the walls in Toyo Ito's 2002 Serpentine Pavilion in London (left) came from a computer program.

Builders also use parametric software to help figure out how to construct complex curved forms such as those that architects designed for the Beijing National Stadium (below and left), which was showcased in the 2008 Summer Olympics. The engineering firm Arup Sport used such a program to calculate the specifications that workers followed when they cut curved steel branches like those in the picture at right, which was taken from inside the stadium during construction.

ANDREW WHEELER; SERGIU TURCANU; TAO IMAGES LTD./ALAMY



Parametric design could change construction methods even more radically in the future. Once software lays out the detailed designs, robotics, three-dimensional printers, and other computerized technologies can be used to execute them.

The façade of the Gantenbein Vineyard in Fläsch, Switzerland, is an intricate brick pattern that looks from a distance like a basket (left). The design required bricks to be placed at precise angles that would have been impossible for a human mason. The firm Gramazio & Kohler built the façade with a robot repurposed from the automotive industry (bottom left).

The rendering at right is a whimsical project by François Roche that suggests future directions for structures built almost entirely by machines. Gigantic three-dimensional printers could fashion intricate biomimetic skyscrapers modeled on coral skeletons.

GRAMAZIO & KOHLER, ETH ZURICH, RALPH FEINER (VINEYARD); R&SIE(N)/ FRANÇOIS ROCHE, STÉPHANIE LAVAUX, JEAN NAVARRO & BENOÎT DURANDIN

Searching for the Future of Television

Google and the geeks from Silicon Valley aim to revolutionize the 70-year-old TV industry. Conquering the Internet was easy in comparison.

By ROBERT D. HOF

Nearly every week from last February until mid-May, Google trotted wide-eyed visitors into a small room at its colorful headquarters in Mountain View, California. Inside were a comfy couch and easy chairs, a tall fabric houseplant in a corner, and a large high-definition television set atop a credenza. Under the watchful eyes of engineers and product managers on the other side of a mirrored window, the visitors would settle in with a wireless keyboard. They would search for and tune in to *All My Children* on ABC, catch a *Glee* episode on the Web, watch a recording of *The Daily Show* from a digital video recorder, or surf over to those witty Old Spice ads on YouTube—all on that nice big TV screen.

The company was testing one of the boldest bets in its 12-year history: Google TV. It is software that aims to give people an easy way to access everything available on regular television channels and the vast sea of content on the Internet, all on the biggest screen in the house—a bid to reinvent television for the Internet age. The initiative was set for its first public demonstration on May 20, and Google's geeks had to make sure the product would appeal to the average viewer, who watches about five hours of television a day. So week after week, the Google TV team would try out countless variations on everything from the look of the search results to the background colors for the screen, hoping to learn what worked best.

Google had good reason to sweat the details. Since the mid-1990s, several costly efforts to bring the Web to the TV have fallen flat. Hybrids such as WebTV Networks, which disappeared into Microsoft in the late 1990s, suffered from myriad problems, including poky network connections, underpowered hardware, and clunky user interfaces. But even if they had worked better, these earlier endeavors would still have suffered from a bigger problem: their developers seemed to forget that most people hadn't bought their televisions to browse the Web. They just wanted to watch TV.

They still do. But now new technologies and an increase in TV-friendly Web content are swelling the variety of programming choices well beyond what's available through their coaxial cable, satellite dish, or DVD player. As the Internet makes inroads into the last great mass medium, millions of people are starting to program their own niche television experiences. For as little as $60, new devices and software from TV makers, startups such as Roku and Boxee, and giants such as Apple have made it a snap to deliver

CAMERIQUE/CLASSICSTOCK/CORBIS (PHOTO); THE HEADS OF STATE (GOOGLE TV LOGO)


GOOGLE TV

online content to any set. In addition to what's available online at no charge, programming can be streamed to TV sets from Netflix for $8 a month or from Amazon Video on Demand starting at $1 per episode.

The Google TV software, which is available on Sony's line of "Internet TVs," on a $400 Blu-ray player, and on a $300 set-top box and keyboard controller from the peripherals maker Logitech, goes further than most other technologies on the market. For now, Google TV is essentially a way to find and view video in a setting that's more comfortable than sitting at a computer. But it also offers a full-fledged Web browser so viewers can reach any website. "All of a sudden, all that content out on the Web, all those millions of channels, are now on your TV," says Rishi Chandra, lead product manager for Google TV.

Even without Google's contribution, the consumer electronics industry has already transformed the TV set into a computer that can be connected to the Internet. That means the future of television is now up for grabs: the screen, the industry, even the meaning of the word. Just as the Internet tore through newspapers, magazines, and music, it's now poised to make television the media battleground of the coming decade. That's why Google knows it has to be involved. If it wants to protect its leading role on the Internet, maintain its prime position in online advertising, and grow into emerging markets, then it can't risk letting other companies control the online experience on the living-room TV. But getting the technology right is only part of what Google needs to do.

The company's rise online was easier in some ways, because the Internet is a completely open platform. Television is not. Moreover, television is run by executives who are loath to change lucrative business models built over decades. U.S. cable and broadcast networks, local broadcast affiliate stations, and cable and satellite operators take in more than $60 billion a year from advertising. In addition, millions of monthly cable and satellite TV bills deliver $80 billion a year in revenue in the United States to operators such as Comcast and DirecTV, according to analysts at the Diffusion Group. Those companies turn around and pay about $23 billion annually in fees to cable networks like ESPN and HBO, which is why pay TV is the largest profit engine for media companies such as Walt Disney, Time Warner, Viacom, and News Corp. Increasingly, the Big Four broadcast networks—ABC, NBC, CBS, and Fox—are demanding, and getting, such fees as well.

Both revenue streams—the one from advertisers and the one from viewers—could be threatened if the medium is fully opened to the Internet. The ability to scour the Web for programming to suit any interest could fracture the audience further, and that would diminish the main attraction TV has for advertisers: its enormous reach. And the more content that is available free, the less incentive viewers have to pay for cable.

In theory, Google might offer a better business model to the television industry, but it has revealed few clues as to its plans for advertising on Google TV. In the absence of definitive plans, the networks have tended to imagine the worst: they fear that the company is out to steal their advertising or disrupt their deals with cable operators. Neither of those things seems likely to happen in the near future, and millions of people already view TV shows on their PCs. But if the TV industry's fears seem excessive, they're also understandable given the travails of publishing in the Google age. As the Internet company tries to please consumers and navigate the TV industry, Google TV could suggest how the battle for the soul of television will play out in 2011 and beyond.

BEYOND A HOBBY

Google TV began with a vision Vincent Dureau had when he joined Google in August 2006 from OpenTV, a maker of set-top-box software, where he had been chief technology officer. His new job was to help run Google TV Ads. That's an initiative, still active, to bring to TV the self-service, auction-style system used in Google's AdSense program, which places ads on mostly smaller websites. For now, the TV Ads system isn't generating substantial revenue for Google or doing much to change mainstream TV; it mainly allows small advertisers to place ads in unsold time slots, such as late at night, or on less popular stations. But Dureau also wanted to fulfill a longtime dream of creating a TV platform that could be improved faster, like a PC or a mobile phone. That would require bringing Web applications and services to the TV. Problem was, the Web and the TV still weren't ready for each other. Even when the first Apple TV device launched in March 2007, for instance, it was mainly for playing video and music from iTunes or a networked computer: it was a "hobby" for Apple, as CEO Steve Jobs called it.

By mid-2007, Dureau saw that this situation would soon change. Home broadband speeds had improved sufficiently to handle video, and wireless home networks were becoming more common, providing Internet connections throughout a house. There was more to watch on the Web, too. ABC had just started streaming some high-definition episodes of shows such as *Lost* and *Grey's Anatomy* online. And YouTube, since bought by Google, was a phenomenon, with visitors watching about 2.5 billion amateur videos and clips of TV shows, some of them illicitly uploaded, every month.

So Dureau, a soft-spoken but intense Frenchman whose palms bear black calluses from propelling his wheelchair, decided to go for it. In October 2007, he made a pitch for Google TV to the company's operating committee, or OC. That's the group of about a dozen executives, including CEO Eric Schmidt and cofounders Larry Page and Sergey Brin, who decide which major projects Google will pursue. Dureau pointed out that there are four billion TV watchers worldwide—a billion more than the number of

Web and cell-phone users combined. Reaching them had obvious potential for Google's search ads or YouTube's video ads. The OC gave a thumbs-up. Dureau immediately began recruiting engineers, and the project got under way in earnest in early 2008.

Since most standard Web pages look awful when viewed on a TV from 10 feet away, Dureau and his team initially assumed they would need to create a "walled garden": TVs would show a subset of the Web tweaked through a custom interface or through curated apps like those offered by previous Web-TV hybrids. In late 2008, about a year into the project, Dureau changed his mind. He had his Apple MacBook connected to a projection screen in a Google conference room before a meeting, and the group started watching YouTube videos. The picture quality was so decent, he recalls, that "we started thinking, 'How is that not television?'" That convinced him: a good chunk of the Web was ready for prime time. So he reversed course and decided to offer the option of using a full Web browser.

Even without Google's contribution, the consumer electronics industry has already transformed the TV set into a computer that can be connected to the Internet. That means the future of TV is now up for grabs: the screen, the industry, even the meaning of the word.

As luck would have it, the company was working on one, which it launched as Chrome in September 2008. That gave Google TV a ready-made way to access the Web. It wouldn't be perfect for many Web pages, which can still be hard to read and navigate from the distance of the couch—but then, neither was the iPhone's version of the Safari Web browser. Yet the prospect of using a mobile device to go anywhere on the Web was so appealing that iPhone users didn't mind the limitations, and Apple had a runaway hit. Google hopes the same will happen on the TV—a typically Googley long shot.

At the same time, Dureau knew Google TV would need a lot of apps, to provide couch-friendly, one-click experiences. Another stroke of luck: just a month after he got the okay for Google TV, the company released its Android operating system, which lets anyone offer applications for mobile phones and other consumer electronic devices. The ability to piggyback on Android makes Google TV more promising than many other Web TV schemes that would bust open television to be remixed, reprogrammed, and remade.

Google made yet another key decision that would set its product apart and get the attention of TV industry leaders. The devices offered by Roku, Boxee, Apple, and others are often described as "over the top," because they offer content over and above what people can get on pay TV. These devices connect to a TV with an HDMI cable, and in order to get the extra content, viewers must switch from the cable feed to a different input. By contrast, Google TV runs right on the television, if you have the Sony model; otherwise, it runs on devices that plug into both a cable or satellite feed and the TV. That allows viewers to search for and access TV and Web content at once. "We didn't want users to have to choose between the Web and TV content," says Dureau. Google touts this design as an example of its effort to place the Web within the TV experience. But it could also wrest control of the main TV screen from cable operators.

By early 2009, using generic Intel desktop computers and full-size keyboards from Best Buy, Google began producing prototypes to show prospective electronics manufacturers. It also worked out a partnership with Dish Network—its first and, so far, only deal with a satellite or cable distributor. That was a breakthrough, because it lets Google TV provide a more comprehensive and personalized TV experience. Dish customers can use the Google product to seamlessly search for content on TV, the Net, and their own DVRs.

Other partnerships came about with the help of Intel, which ended up becoming the microprocessor supplier for Google TV devices; the company had been touting "smart TV" for years in hopes of getting its chips into new kinds of electronic gear. Logitech, in the midst of a big push into universal TV remote controls, was already talking to Intel about a video-calling device for the television. Executives at Intel, realizing that they might coördinate efforts with Google TV, set up meetings between the two companies in mid-2009, and Logitech soon signed on to create a Google TV set-top box. Intel also connected Google with Sony, which became Google TV's other electronics partner. In September, as Sony and Logitech began hiring more engineers to work on their products, Chandra joined the Google TV team to accelerate the push to the finish line.

GIVE PEOPLE WHAT THEY WANT

Now it was time to turn Google TV into something tangible. That meant Google and its partners had to design a user interface that would work for the TV, without any of the glitches and impen-

MILLIONS OF CHANNELS

No longer must viewers depend solely on what their pay-TV providers offer for entertainment. Here are six examples of services or devices that bring video and other Internet content to the TV.

GOOGLE TV

Pro: Full browser provides easy access to the Web

Con: It's expensive, and networks block shows on their websites

BOXEE

Pro: It streams many video formats smoothly

Con: Software glitches plague early version

APPLE TV

Pro: It's small, elegant, and easy to use

Con: Content sources are limited

XBOX 360 (SHOWN), PLAYSTATION 3, AND WII

Pro: These consoles offer rich gaming experiences

Con: Web access is limited

etrable error messages that plague computers—something that has consistently eluded Silicon Valley's engineers.

They also had to figure out how to anticipate the expectations of an everyday video viewer. Part of the dream for Google TV and similar services is that Internet-connected TVs could make television a social experience again, as it was when families gathered around their sets to watch programs together. The next-generation TV could eventually become a big-screen hub for the house; while you relax on the couch, you could video-call your mother during an ad or show full-screen high-definition videos of your children to your friends, whether they're sitting next to you or on their own sofa in another country. One early tester used Google TV to shop

ROKU

Pro: The price starts at $60, and the product is dead simple

Con: There's no official YouTube channel

CONNECTED TVs

Pro: Internet is built in—no extra box required

Con: Apps can run slowly on underpowered hardware

for a car with his whole family—something that wouldn't work well on a little laptop.

Already, Nielsen has found that a lot of viewers—60 percent!—use the Internet while they watch TV. In fact, on average they spend three and a half hours a month doing those things at the same time, up 35 percent from the previous year. Often people are texting friends or posting on Twitter about the shows they're watching; during MTV's Video Music Awards in September, artists getting awards were the subject of 2.3 million tweets. Now some adventurous content creators are embracing this trend: in October, actor Seth Green launched a reality Web series called *Control TV* in which viewers voted in real time on such questions as what the main character should eat for breakfast and whom he should date. In time, the technology could even learn what you'd like it to show you. Why not, for example, a TV that can recognize your voice when you walk into the room and deliver video and other services utterly different from those your spouse would see? Or an app that brings up your fantasy football stats during a game?

Google TV can't do such tricks yet. But by May 2010, the company felt it was time to go public with the concept, if not a finished product. When Chandra took the stage for a demonstration before thousands of people at Google's annual I/O conference for software developers, the company showed how much the TV project mattered. Onstage with its own chief, Eric Schmidt, it assembled a star cast of partner CEOs, including Howard Stringer of Sony, Paul Otellini of Intel, Charles Ergen of Dish, and Brian Dunn of Best Buy.

Through the summer, Logitech's 40-person Google TV team in Fremont, California, hunkered down in a sea of cubicles known as the Pit to refine the design for its Google TV product, which is called the Revue. One wall was lined with printouts of all the Google TV setup screens, on which engineers would plaster sticky notes suggesting fixes or improvements. Meanwhile, Chandra was wrapping the Google TV prototype gear in towels and cramming it into a suitcase to demonstrate to other potential partners across Asia, Europe, and the United States.

Finally, on October 6 at San Francisco's Clift Hotel—as it happens, just a mile and a half south of the lab where Philo T. Farnsworth transmitted the first electronic television image in 1927—Logitech and Google debuted the first Google TV product to the press and the world. Sony's TV would soon follow. But the glow of accomplishment wouldn't last long.

VERSION 2.0

Slumping into a chair in a cubicle where he often shows Google TV to potential partners, Rishi Chandra sighed. "Every day is a new fun day," he said with a weary sarcasm. The previous day, October 21—just days after the products from Logitech and Sony hit the stores—ABC, NBC, and CBS had started blocking Google TV users from viewing shows on their websites. That exposed a stark reality of TV's business model: if people were going to watch programming on a fancy television, the networks wanted them to watch through cable or satellite, because that's where the real money flows. Sure, the networks show ads when they run pro-

grams on their websites, but online ads aren't yet as lucrative as TV ads, because they can't promise the massive audience reach of TV. Even more important, cable operators might rethink those juicy fees they pay to run the networks' shows if they're available free on Google TV. "There's no constitutional right to get *NCIS: LA* through the Google TV box," Zander Lurie, senior vice president of strategic development at CBS, told a TV conference this fall.

It was a big blow. Without access to the latest shows—which often appear on the networks' websites exclusively as soon as a day after being broadcast—Google TV might look crippled to prospective buyers. And the company had few options for fixing the situation on its own. It could go the same route as Netflix and pay the networks for the rights to their online content, but then Google would become a provider of shows, not an independent conduit. Chandra had to deal with the fallout. Google TV respects TV's established business dynamic, he insisted. It was a statement he had clearly recited many times—and one that might sound familiar to publishers struggling to contend with Google's impact on print media. "Our product is designed assuming you have cable," he said. "The best content is on cable. People are relatively satisfied. What we're trying to do is take that experience today and enhance it with a whole lot of other content you just can't deliver through cable technology."

Many viewers prefer to pull in content when they want it, rather than glue themselves to the couch for appointment TV. Yet the TV advertising model still assumes that people are watching live content and commercials pushed out to them.

Some cable networks—such as Time Warner's stable, which includes TBS, TNT, and HBO—are at least tentatively embracing Google TV. "We don't want to be in the device-blocking business," says Jeremy Legg, senior vice president of business development and multiplatform distribution for TBS. "We don't think that's what the Internet is about." However, HBO has a measure of protection: to reach HBO's shows online, Google TV users have to log in and "authenticate" themselves as cable subscribers. In other words, Google is asking its users to prove that they are still putting money into one of TV's main revenue streams rather than getting most of their video online and cutting the cable cord.

Bypassing pay TV is precisely what more than a few people seem to be doing. U.S. cable and satellite TV companies together lost 119,000 subscribers in the third quarter of 2010, according to the market research firm SNL Kagan. That's a minuscule drop compared with the approximately 100 million subscribers overall, and no doubt it was chiefly because of the poor economy. But it was the second drop in a row, after a first-ever decline in the second quarter. Meanwhile, Netflix added 4.7 million new customers in the first nine months of 2010.

These subscriber losses may not be over for cable and satellite companies, either. A September survey of 2,000 Americans by the market researcher Strategy Analytics found that 13 percent of them planned to drop their cable in the next 12 months. "My kids think I'm crazy for being in the pay-TV business, because they don't pay for TV, and [they] watch a lot of TV and movies [online]," Dish Network's Ergen complained during a conference call with financial analysts in November.

Even customers who still have cable are rapidly altering their behavior in a way that represents a fundamental challenge to the television business. Already, with help from DVDs and the DVR, many viewers have decided they'd prefer to pull in content when they want it, where they want it, rather than glue themselves to the couch for appointment TV. As Internet TV devices give viewers even more choices, says W. Russell Neuman, a professor of media technology at the University of Michigan, "push technology is shifting completely to pull." Yet the TV advertising model still assumes that people are watching live content and ads pushed out to them.

Through Google and other players, interactive TV, like the Internet, could offer better targeting for advertisers. People could be shown an ad that their viewing habits indicate is probably relevant to them—and networks could thus command higher ad prices for smaller audiences. (In the advertising industry, this is called "efficiency.") Hulu, a joint venture of the parent companies of NBC, Fox, and ABC that streams episodes of many network shows online without charge, boasts that Nielsen research finds people much more likely to recall the messages they've seen through targeted ads on its service than they are when the same ads air on primetime broadcast TV. "We're charging higher rates for more targeted ads," Hulu CEO Jason Kilar said recently.

But Google has offered no specific plans of its own yet, and ad buyers and ad sellers each have reasons to be suspicious of targeted advertising. Brands that do the most TV advertising doubt that targeted ads will reach a big enough audience to be effective—the key reason they're continuing to spend on television. Networks worry that the Internet's emerging method of targeting people according to their interests or online activity—a growing alternative to the traditional media model of buying space on sites or shows that promise a particular audience—could turn their ad slots into lower-priced commodities.

H. ARMSTRONG ROBERTS/CORBIS

Having observed the effects of more efficient advertising in media like magazines and newspapers, networks and pay-TV companies are experimenting with new business models, mostly subscription-based. Hulu has blocked access from Boxee—and now from Google TV. It's rolling out an $8-a-month service in hopes of creating a new revenue stream beyond ads. Cable networks are also exploring versions of the authentication model that HBO requires on Google TV. The cable companies call their version TV Everywhere, but the point is the same: it will let viewers get shows online once they prove they already subscribe to cable.

Such efforts may well keep most people watching conventional cable and broadcast TV for some time to come—especially if products such as Google TV fail to appeal to the mass audience. And initial reviews have been mixed: for all Google's research and user testing, critics say it's still too much like a computer. Moreover, Google TV and its rivals have few made-for-TV apps to offer, and there's only one killer app for interactive TV so far: Netflix. More could come in the first half of 2011, when Google will invite outside developers to create Google TV apps and offer them on its Android app marketplace. For now, says Vivek Khemka, Dish's vice president of customer technology, "it's definitely not a product that I can market with a tag line." Google's Chandra concedes, "This is very clearly a Version 1.0 product." Google and Logitech are working on 2.0, which is likely to come out in 2011, although neither company will disclose its plans.

But in the meantime, it might be easy for TV's beleaguered leaders to lose sight of the bigger picture. Disruptive technologies nearly always beget new ways to profit, sometimes even for the incumbent players whose business model is being upended. Some of them do recognize that potential. "This is a terrific time in the living room," says CBS's Lurie. "People are consuming more video. So there's more opportunity for content providers to get paid."

The upshot, says Chandra, is this: "Your TV is going to get better every day." Google TV and its ilk may look like threats to the TV business right now, but odds are that ultimately—one way or another—they will help make television an even more pervasive part of our lives. **tr**

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The Human Genome, a Decade Later

Ten years after scientists finished mapping our DNA, they have many unanswered questions.

By JON COHEN

ON JUNE 13, 2010, the *New York Times* ran a front-page story about the hyping of genomics. Headlined "A Decade Later, Gene Map Yields Few New Cures," the article asserted that the Human Genome Project, the results of which were announced at a White House press conference in June 2000 and published in detail in February 2001, had yet to deliver on its promise to find the root causes of many common diseases. The genome, the story argued, held more complexity than many scientists had imagined, making it difficult to isolate the functions of the three billion DNA units, or base pairs, whose sequence the project had determined. Other journalists, and bloggers, soon weighed in somberly on the dearth of results from the project, which had taken 13 years and $3 billion to complete.

The coverage outraged Eric Lander, who was one of the leaders of the Human Genome Project and now directs the Broad Institute, a leading biomedical-research center that is a collaboration of Harvard University and MIT. "I'd like to see a quote where I ever hyped it," says Lander. "I'm on record saying this is going to take a long time, and that the next step is to find the basis of disease, and then you have to make drugs. I said this is going to help our children's children. Going from the germ theory of disease to antibiotics that saved people's lives took 60 years. We might beat that. But anybody who thought in the year 2000 that we'd see cures in 2010 was smoking something."

Lander cites a long list of technological advances and scientific insights that have come in the project's wake. The price of sequencing DNA has dropped from hundreds of millions of dollars per person to mere thousands. The number of single-gene aberrations known to cause disease—illnesses

Illustration by PETER CROWTHER

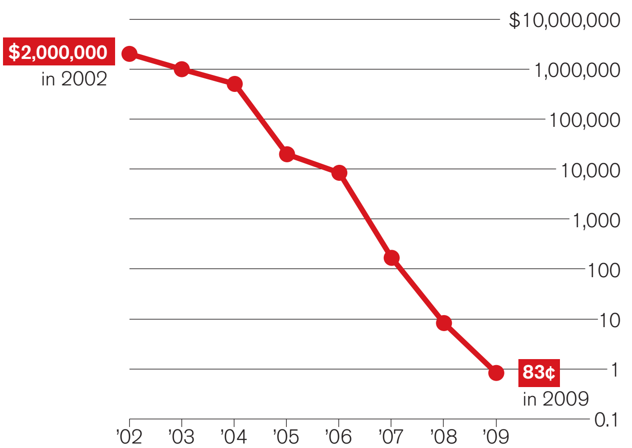
that are invariably rare and follow a simple Mendelian pattern of inheritance—has jumped from around 100 to nearly 3,000. The growing list of common diseases that have been traced to multiple genetic variants includes everything from types of blindness to autoimmune diseases and metabolic disorders like diabetes. Studies have linked more than 200 genes to cancer—nearly three times the number that had been known of before.

Lander concedes that many features of the human genome have only recently come into clear focus—features suggesting that it's more of a moving target than was previously thought. Genes, traditionally described as regions of DNA that code for proteins, have long been a main focus of researchers, of course. Recent studies, however, have emphasized the extraordinary power of DNA regions that do not hold the code for a protein itself but, rather, control the on/off switches that direct gene "expression," or the extent to which that protein is actually produced. An entire world of microRNAs has moved to center stage because of their ability to silence genes.

The fledgling field of epigenetics is showing how two organisms with identical genetic sequences can have different characteristics because of heritable non-DNA factors like methyl groups, which are common reactive chemical entities that alter the behavior of genes. Many diseases have now been linked to extra or missing copies of genes, a phenomenon called copy-number variation. Researchers are also paying increased attention to transposons and other mobile genetic elements that can cause mutations, sticking themselves inside genes or deleting them altogether.

SEQUENCING ON THE CHEAP

The cost per million DNA base pairs has plummeted in recent years.



Source: Peter A. Carr and George M. Church, Nature Biotechnology, *2009*

None of these factors are newly discovered, Lander stresses. But during the past 10 years, features once considered bit players have taken on the status of lead actors, now often commanding as much attention as genes themselves. So indeed, the genome contains far more inconvenient truths than was supposed a decade ago. The very idea of what we inherit and what we pass on has changed.

Yet it is "the height of silliness," Lander contends, to suggest that this complexity makes it more difficult to develop diagnostics, treatments, and cures. He gives the example of recent studies that have linked nearly 100 genes to lipid metabolism. One of these, which has a tiny effect by itself, is the target of the statin drugs that many people take to lower cholesterol. That dozens of genes are involved in a problem, then, does not mean you need dozens of drugs to attack it; rather, he says, it reveals that there are dozens of ways to intervene. "All biological science works by collecting the complexity and recognizing it is part of a limited repertoire of events," he says. "What's exciting about the genome is it's gotten us the big picture and allowed us to see the simplicity."

The main challenge today is to catalogue and bring order to what often looks like chaos—a task that is hardly surprising to those who have worked on the genome for years. As Marc Vidal, a geneticist at the Dana-Farber Cancer Institute in Boston, says, "From the mid-1990s, there was a strong sense that just sequencing the genome wasn't going to be enough."

SHORTCUTS

The increased understanding of the human genome has been driven largely by rapid advances in technology. And the single most profound advance has been in the cost and the speed of sequencing. "The cost dropped by a factor of 10 every year for the last five to six years, so it's a truly amazing exponential decrease compared to the computer industry," says Harvard University geneticist George Church, who helped develop many key sequencing technologies.

Even with the advances in technology, however, it still costs in the neighborhood of $20,000 to sequence a complete human genome—a lot less than $3 billion, but still a high price tag. And the field's main strategy for connecting genetic makeup to observable traits—genotype to phenotype—is to compare large numbers of individuals in hopes of identifying the differences that might explain, for example, why one group develops schizophrenia and another does not.

During the past decade, genome-wide association studies, which screen many individuals in order to identify genetic variations shared by people with a particular disease, became the standard technique for comparing DNA from large groups of people without the need for complete sequences. These studies have received intense scrutiny: they were the focus of the *New York Times* article Landers assailed and of many critiques in the scientific literature.

CHARTS BY TOMMY McCALL

> "All biological science works by collecting the complexity and recognizing it is part of a limited repertoire of events. What's exciting about the genome is it's gotten us the big picture and allowed us to see the simplicity."

The first round of these studies attempted to discover disease genes by focusing on mutations involving variations in a single DNA base pair—mutations that were relatively common, affecting more than 5 percent of the population. The idea is that these common variants, called single-nucleotide polymorphisms (SNPs), tend to occur in certain patterns within the genome and get passed down together. Thus, they serve as markers for surrounding DNA: people who share sets of SNPs, which are known as haplotype blocks, should turn out to share the same versions of specific genes. A study called the HapMap project, which looked at more than 200 people from four different populations, established a catalogue of human variation that researchers hoped would allow genome-wide association studies to find everything from genetic factors that make people sick to evolutionary traits in populations. The associations between specific haplotypes and traits did not pinpoint genetic causes but spotlighted small regions on chromosomes—regions that were thought to hold the answers.

But it turned out, as Duke University geneticist David Goldstein argued in a critique published in the April 23, 2009, issue of the *New England Journal of Medicine*, that "common variation is packing much less of a phenotypic punch than expected." A study on height, Goldstein noted, had found 20 variants that together explained only about 3 percent of the variation found in humans. These sorts of results have led some researchers to scratch their heads about "missing heritability" and the "dark matter" of the genome. A key problem in using genome-wide association studies to search for the genetic roots of disease, Goldstein contended, is that many common diseases might be attributable to a number of rare variants rather than to a few common ones. He also reasoned that these studies will have little relevance in cases where large numbers of genes each make a small contribution to a disease, because "in pointing at everything, genetics would point at nothing."

An essay in *Cell* a year later by Mary-Claire King and Jon McClellan of the University of Washington in Seattle fired another salvo at the genome-wide association studies. They agreed with Goldstein about the role of rare variants in disease, and they further argued that the same mutation might cause different illnesses in different people, while different mutations might all cause the same illness. Moreover, they wrote, if a mutation is so rare that it's found only in a few individuals and their immediate families, analyzing thousands of unrelated people will miss the genetic roots of disease. They concluded that the number of genetic pathways to disease is "far greater than previously appreciated."

Such criticisms miss the point, according to geneticist David Altshuler of Massachusetts General Hospital in Boston, who says the attacks on genome-wide association studies ignore abundant evidence that these studies have uncovered important links to disease. Some studies that tried to tie common variants to common traits found very weak associations, he concedes, but he points to several that revealed relatively large genetic factors in diabetes, heart disease in South Asians, kidney failure in African-Americans, and sickle-cell anemia in Europeans, among other illnesses.

Altshuler acknowledges that genome-wide association studies have their deficiencies, but he says that given the cost of sequencing, this shortcut has been a great boon to science. "In 10, 20 years, will you put a drop of blood in a machine and get a perfect sequence, and that's all you do? Yes," he says. "In 2010, is that all you should do? Not unless you're rigid. It costs a lot more to sequence."

Even the complete DNA sequence assembled by the Human Genome Project had a critical limitation: each individual harbors much more variation than it detected. We have a diploid genome, with one chromosome inherited from each of our parents. Thus, we have two copies each of 23 different chromosomes, but the Human Genome Project simply sequenced 23 chromosomes—a composite set assembled from several individuals. In 2007, Craig Venter, who led a private sequencing effort that was a leading competitor to the Human Genome Project, worked with Stephen Scherer, a medical geneticist at the Hospital for Sick Children in Toronto, to sequence his complete diploid genome and found more than four million differences between the chromosomes he inherited from his mother and his father. Extrapolating from this finding suggested that the amount of variation between humans was not 0.1 percent, as the Human Genome Project had estimated, but more like 0.5 percent. "For all studies, you should look at the genome in a diploid context," says Scherer. "That's where we need to go."

THE CELL

Over the last decade, researchers have charted many nuanced features of the genome, and they are now fine-tuning sequencing methods and other technologies that will expand their understanding of the genomic landscape. But by and large, the dream of applying that knowledge to benefit human health remains just that. Finding usable medical information amid the huge amount of genomic data is an immense challenge.

THE GENE FACTOR

Researchers have found only a fraction of the genetic component to common diseases and traits.

DISEASE/ TRAIT	OVERALL HERITABILITY	PERCENTAGE OF OVERALL HERITABILITY EXPLAINED	NUMBER OF GENETIC LOCATIONS IDENTIFIED
AMD*	45% to 70%	50%	12
Crohn's disease	50% to 60%	23%	71
Type 2 diabetes	30% to 70%	10%	38
Height	60% to 80%	15%	180

*Note: *Age-related macular degeneration*
Sources: Wei Chen et al., PNAS, *2010 (AMD); Andre Franke et al.,* Nature Genetics, *2010 (Crohn's disease);*
Benjamin F. Voight et al., Nature Genetics, *2010 (type 2 diabetes); Hana Lango Allen et al.,* Nature Genetics, *2010 (height)*

A variety of different schemes now attempt to make sense of these mountains of data, aiming to catalogue all proteins (the proteome), RNA molecules (the transcriptome), metabolites (the metabolome), and interactions (the interactome). But some researchers argue that it's crucial to put this vast collection of data in biological context. Sydney Brenner, a scientist at the Salk Institute for Biological Studies in La Jolla, California, and the University of Cambridge in England, takes a particularly harsh view. "This 'omic' science has corrupted us," says Brenner, who won a Nobel Prize in 2002 for leading a project that four years earlier completed the first entire sequence of a multicelled organism, the worm *Caenorhabditis elegans*. "It has created the idea that if you just collect a lot of data, it will all work out."

Brenner contends that the organizing principle for thinking about the genome can be found in the cell, the basic unit of life. In an essay he published in the January 12, 2010, issue of *Philosophical Transactions of the Royal Society B*, Brenner outlined a project called CellMap, which would catalogue every type of cell in the body and detail how different genetic regions (not genes) behave in each cellular environment. He compared it to a city map that identifies each house, the people who live inside it, and the interactions within and between the houses. "I think we should be doing genetics, not genomics," says Brenner. "When you do genetics, you are focusing on function. When you do genomics, these are just letters and numbers. Nobody bothers about the connections."

A cell-centric approach is only one possible route to understanding genomic data. But the conviction that DNA sequences and other genetic information won't be medically useful until they are better connected to biology is a common one among scientists. Instead of starting with DNA and hoping to determine how it leads to complex diseases, they say, the focus needs to be on patients and what, biologically speaking, has gone wrong; then researchers can try to understand the underlying genetics. "Let's start with the patient and work backward," says Altshuler. "Something that has profoundly diminished the biomedical impact of [genomic] work is the unquestioned faith that everything can be learned in reductionist approaches and model systems. We need them, but we need substantial investment in studying the human being."

Harvard's Church agrees that not enough has been done to link genomic data to observable traits. In 2004, he launched a Personal Genome Project that ultimately aims to sequence the DNA of 100,000 people who voluntarily share their medical records and facts about their lifestyles. Without that information, understanding how an individual's DNA sequence causes or is linked to diseases is problematic, says Church: "It's a barrier to interpretation. It ends up oversimplifying what has to be one of the most complicated biological problems—how humans work."

Daunting as the challenge has been to uncover the genetic basis of diseases, Altshuler says great strides have been made over the past decade. "The era of mapping genes for diseases is going to be over very soon," he predicts. "I'm not sure whether it will be five years or 10 years—and I don't mean we'll explain all the heritability. But once we've sequenced a hundred thousand people or a million, we'll know what there is to know."

A decade after the completion of the Human Genome Project, scientists are still finding fundamental surprises in the way we inherit diseases *(see "The Genome's Dark Matter," p. 52)*. Still, despite the unknowns, researchers are beginning to use genome data to unravel one of medicine's greatest mysteries: how and why a cell turns cancerous *(see "Cancer's Genome" p. 46)*. The gap between the promise of the Human Genome Project and the realization of that promise in the clinic will surely narrow as researchers discern the complex and subtle details of the genomic landscape and the conditions that shape it. That this is taking time should come as no surprise. As Lander says, "When people say the genome is so much more complicated than we thought, you have to step back and say, 'How simple did you think it would be?'" tr

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Cancer's Genome

For the first time, scientists can track the precise genetic changes behind an individual case of cancer. Such information provides a picture of how tumor cells originate and evolve. And it could change the way we treat the disease.

By EMILY SINGER

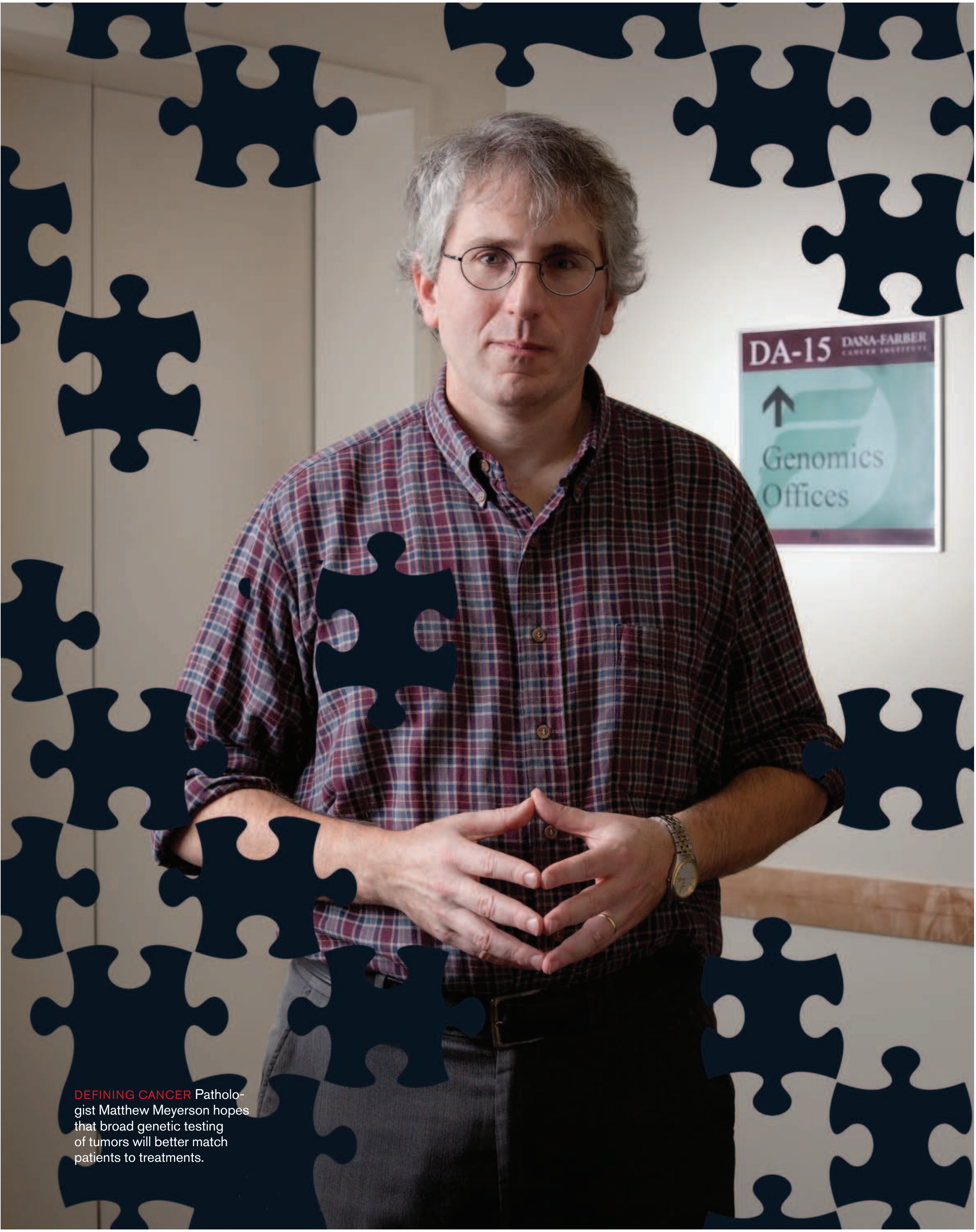
When the patient—a retired physician—walked into oncologist Janessa Laskin's office at the British Columbia Cancer Agency in October of 2008, both of them knew he was dying. He had a rare type of cancer, adenocarcinoma of the tongue, which had metastasized to his lungs. Laskin had two choices for treatment. Traditional chemotherapy could prove dangerous to the 77-year-old man and carried little chance of success. Targeted therapies had been developed to attack genetic dysfunctions found in some other types of cancer, but they had never been tested in his variety.

Meanwhile, across the street at the agency's Genome Sciences Centre, bioinformatics director Steven Jones and his collaborators happened to be finishing a herculean task. They had used the center's bank of sequencing machines to read the entire DNA sequence of a series of ovarian tumor cells, one base, or letter, at a time. The researchers hoped that comparing the order of these chemical units in the DNA of the cancer cells and the patients' healthy cells would reveal the genetic anomalies that gave the cancer its destructive powers of growth and invasion.

The patient asked Laskin's colleagues at the Genome Sciences Centre if there was anything they could do to help him, and Jones and his team suggested a plan, which the patient and Laskin decided to follow. The researchers would take a sample of his tumor, isolate the DNA, and feed it through the sequencing machines, searching for clues that might advise them on how to treat it. They spent the next three weeks working around the clock. After sequencing the DNA, they used the genetic mistakes they had identified, along with their knowledge of the molecular pathways that have been implicated in cancer, to create a model of what might be going wrong in this patient's body. They painstakingly narrowed the search until they hit on a genetic defect that increases the activity of a molecular pathway that has been linked to the growth of cancer cells.

Laskin began treating her patient with a drug that inhibits the activity of the defective gene, and "within a month we saw 20 percent shrinkage of his cancer, whereas the previous six weeks it had undergone 20 percent growth," she says. The cancer stabilized for six months, but then it started to grow again. The physicians tried a second set of drugs, again chosen with the guidance of the genome model. For another four months, the cancer stayed under control. Then once again it began to spread, with new tumors sprouting in the patient's lungs and neck. Laskin performed a biopsy on these tumors and had their DNA sequenced "to see if we could explain what had changed and predict the next round of drugs," she says. "But unfortunately, the cancer was growing really fast." Unable to wait another three weeks for the results, she treated him with standard chemotherapy. The patient died in November of 2009.

Photograph by KEN RICHARDSON



DEFINING CANCER Pathologist Matthew Meyerson hopes that broad genetic testing of tumors will better match patients to treatments.

The case, the first in which scientists used the entire DNA sequence of a tumor to help choose drugs for a cancer patient, provides a peek at both the great promise and the difficulties of using our increasingly detailed knowledge of cancer genetics to inform treatment. In many ways, cancer cells are rapidly evolving genetic mistakes. They originate from normal cells in the body, starting with the same genetic makeup as any other cell. But every time a cell divides and copies its DNA, it has the potential to make errors. Accumulate the wrong assortment of these mistakes—in genes that influence cell growth and survival, for example—and you get a cell that can outgrow and outlive its healthy neighbors. Cancer cells continue to mutate through the course of the disease, some ultimately acquiring the ability to break free of the tissue in which they originated and enter the bloodstream. Until recently, physicians have lacked the information to understand this process, let alone to make calculated attacks against its most dangerous aspect: metastasis, the spread of cancer from one part of the body to another. "A patient's tumor is a living thing, changing all the time," says Matthew Ellis, an oncologist at Washington University School of Medicine. "We have never been able to track that completely."

By using DNA sequencing to decipher the precise nature of these changes, scientists hope to understand the ever-evolving cells. The results could lead to better diagnostic tests and more accurate prognoses, distinguishing patients whose cancer will probably not grow further from those whose disease is likely to spread and who would benefit from more aggressive treatment. And as scientists accumulate a list of mutations linked to cancer, they can map them against the complex molecular networks in the cell and begin to delineate the specific pathways that play a central role in the disease. With this map in hand, they will be able to tell when superficially similar types of cancer, such as two lung cancers, have different molecular causes. Then they'll be able to design safer and more effective medicines and target them specifically to the patients who are most likely to respond. "In the next few years, we'll create an essentially complete catalogue of mutations linked to each different type of cancer," says Michael Stratton, who heads the Cancer Genome Project at the Wellcome Trust Sanger Institute, in the United Kingdom. "We will understand all the genes that can generate cancer and have a list of mutated genes that may be potential drug targets."

This vision epitomizes the promise of personalized medicine—treatment based on a patient's individual genetics and other molecular factors. But it also suggests its challenges. It's now clear that thousands, perhaps millions, of genetic mutations are capable of triggering cancer. Capturing that information is feasible with existing technology. But understanding it is a different matter. "We really don't have the tools to take advantage of this information today," says Tyler Jacks, director of the David H. Koch Institute for Integrative Cancer Research at MIT. And until those tools are available, no one will be able to answer the crucial question: whether a detailed map of a patient's cancer will actually help that person live longer.

MAP MAKING

About seven years ago, Matthew Meyerson, a pathologist at the Dana-Farber Cancer Institute in Boston, began getting desperate calls and letters. Meyerson had recently discovered that lung cancer patients with a mutation in a gene for the epidermal growth factor receptor (EGFR) were likely to respond to specific drugs, and patients wanted to find out where they could get tested for the mutant gene. But no such test existed yet (one was introduced in 2005). Over the next few years, Meyerson made similar findings about more and more mutations. "Patients and physicians were both writing to us for help in getting these diagnostic tests," he says. "But with few exceptions, they were not available."

Despite the huge volume of knowledge generated by research labs over the last few years, only a handful of genetic tests are currently available to most cancer patients, and those typically test only one or two genes. So about five years ago, Meyerson and Levi Garraway, an oncologist and scientist at Dana-Farber, set out to create a more comprehensive test for cancer-linked mutations. The goal was to identify genetic signatures, encompassing hundreds of mutations, that would help physicians diagnose cancers on the basis of molecular traits rather than the way cells look under a microscope. Some genetic classification was already under way—breast cancer patients are routinely tested for markers such as the HER2 protein, which predicts who will respond to the drug Herceptin. But as scientists began discovering a much broader array of genetic mutations linked to cancer, oncologists needed a way to screen individual patients for numerous mutations.

This type of screen is necessarily expensive. Because scientists want to pin down how cancer cells differ genetically from normal ones, they must sequence the DNA from both healthy tissue and tumor tissue, doubling the cost of sequencing. To make matters even more complicated, tumor tissue itself is often a mix of normal cells and cancer cells. Scientists typically run healthy DNA through the machine 10 to 40 times to make sure they can piece together an accurate sequence, but Gordon Mills, chair of the department of molecular therapeutics at M. D. Anderson Cancer Center, in Houston, estimates that DNA from cancer tissue may need to be sequenced a thousand times in order to detect rare mutations that could make tumors resistant to drugs.

When Meyerson and Garraway began developing their test, in 2005, it cost more than a million dollars to sequence a human genome. So the researchers chose to limit their test to certain "hot spots"—regions in the genome that were known to harbor a high concentration of cancer-causing mutations. They also chose a relatively cheap technology, called mass spectrometry, to analyze DNA.

It could detect mutations that had been previously identified, but it couldn't uncover new ones. By 2008, however, a revolution in DNA sequencing technology had made it possible to read entire cancer genomes affordably, and cancer researchers quickly began such experiments. As the cost of the technology continues to plummet (sequencing a human genome now costs about $10,000 to $20,000), hundreds of cancer genomes are being sequenced in labs around the world, adding to the database of cancer-linked mutations.

The picture emerging from sequencing studies suggests that the genomics of cancer are even more complicated than scientists had supposed. A few years ago, researchers thought that about five to seven mutations were needed to trigger the uncontrolled cellular proliferation that defines the disease. But recent estimates are as high as 20 in some cancers, and on average scientists are finding five to 15 mutations involved. And the vast majority of newly discovered mutations are rare, occurring in fewer than 5 percent of specific cancers. Indeed, each newly sequenced cancer genome reveals mutations that have never before been seen.

It's not yet possible to analyze and interpret cancer genomes on a scale large enough to make this approach a routine part of treatment. But Foundation Medicine aims to take a step in that direction: the company will focus on a subset of genes, a somewhat easier task. Part of the company's product will be a database that compiles the rapidly evolving scientific literature on a number of specific mutations and the way they affect a patient's response to different drugs. The software will need to predict which mutations in a tumor cell's DNA actually drive the cancer, and which are genetic mistakes of little consequence. And it will need to cope with mutations so rare or novel that at most a handful of studies offer any basis for predictions. (In such cases, researchers typically try to predict the impact of a mutation by looking at how it affects the structure and function of the protein the gene produces, and then examining the role this protein plays in the cell's various signaling networks.) Along with the database, Foundation Medicine is building a user interface to help oncologists interpret information.

Alexis Borisy, a partner at Third Rock and Foundation's acting chief executive officer, is careful to say that the software won't tell physicians what to do. Rather, it will provide layers of information to help them make choices about which drugs and other treatments to try. Only a handful of genetically targeted cancer drugs are widely available to patients today, but Borisy contends that Foundation's test will be useful even when it doesn't point to any of those medications. Hundreds of targeted drugs are now in human testing, so patients who test positive for certain mutations could be directed toward appropriate clinical trials. In addition, some more traditional cancer drugs, which are currently prescribed without genetic testing, are known to act on specific molecular pathways. Physicians who find that their patients' cancers involve these pathways could suggest trying these drugs.

Still, not everyone will benefit. According to Borisy, Foundation researchers who have begun evaluating an early version of the company's test say their results suggest that about half the patient tissue samples analyzed would yield plausibly "usable" information, meaning that the analysis might suggest a particular class of drugs or better define the type of cancer. (The proportion will grow as pharmaceutical companies develop new targeted drugs.) The company plans to begin testing patients early next year, in collaboration with academic medical centers and pharmaceuti-

> "We really don't have the tools to take advantage of this information today," says one researcher. Until those tools are available, no one will be able to answer the most crucial question: whether a detailed map of a patient's cancer will actually help that person live longer.

BUILDING A FOUNDATION

Early in 2010, Garraway, Meyerson, and two colleagues from the Broad Institute—its director, genomics pioneer Eric Lander, and Todd Golub, an expert on cancer genomics—started Foundation Medicine with funding from a Boston-based venture capital group called Third Rock Ventures. The startup's goal is to create a real-world, clinical-grade test that will help physicians determine not only whether someone has one of the growing number of mutations implicated in specific cancers but how severe that patient's cancer is and which drugs it is likely to respond to. Foundation's test will use sequencing technology to identify all the mutations in hundreds of genes that have been linked to cancer in previous studies.

Because the test encompasses so many genes, Foundation's product will be entirely different from the single-gene tests in use today. These are fairly simple to interpret: if a patient has a particular mutation, he or she will probably respond to a certain drug. But analyzing the meaning of hundreds of mutations simultaneously is orders of magnitude more complex. To go through the genome of Laskin's cancer patient, Steven Jones needed a large team with diverse expertise in medicine, oncology, genomics, and information technology, and the process took three weeks.

cal companies. As evidence builds that the test improves patient care, "we expect it to spread to the broader oncology community," Borisy says.

Foundation Medicine's test will initially read the DNA sequences of a limited set of cancer-linked genes, but the company expects to sequence the entire genome of patients' tumor cells as soon as the technology becomes cheap enough. The cost of sequencing is quickly coming into line with that of other medical tests and cancer treatments; an MRI scan, for example, costs about $6,000, and cancer patients typically have several. Still, if experts like Gordon Mills are correct, it will take hundreds of sequencing runs to analyze a patient's cancer DNA accurately enough for medical decision making. In that case, genome-wide sequencing of patients is at least several years off.

THE BURDEN OF PROOF

In 2001, entrepreneur Mark Levin, an early proponent of personalized medicine, made a grand prediction to *Technology Review*: "Over the next five to 10 years, we're going to see an explosion of not only [diagnostic] tests, but the integration of tests and therapy for personalized medicine" *(see "Medicine's New Millennium," December 2001).*

Levin had bet big on that idea, founding Millennium Pharmaceuticals in the early 1990s; the drug development company wanted to create personalized therapies based on knowledge of the genome. The predicted explosion has so far been more of a trickle, but Levin, who went on to cofound Third Rock Ventures, is optimistic that the time is finally right. "When we founded Millennium, the technology was still primitive; there was not enough data, and not enough people in the industry believed in it at the time," he says. "It's been 20 years since this really all started, but it's just now coming together where we can do this cost-effectively and make a big difference for patients." (Millennium was acquired by Takeda Pharmaceuticals, Japan's largest pharmaceutical company, for $8.8 billion in 2008.)

Levin believes that Foundation Medicine will finally realize his vision of personalized medicine in cancer treatment. Indeed, oncology is already more personalized than most areas of medicine. "Cancer treatment, more than other diseases, has been based on a molecular understanding of the disease," says Michael Stratton. "And that is increasing all the time."

But many of the questions that have plagued personalized medicine for the last 20 years remain unanswered. No one yet knows whether developing complex genetic profiles will help patients live longer, healthier lives. The answer depends on a number of factors: whether drugs exist to target an individual's genetic quirks and whether such drugs work better than ones that aim at more widespread cancer-causing mechanisms. It may turn out to be practical to develop only drugs that tackle the more common mutations—say, those present in 5 percent or more of certain cancers. In that case, patients with rare mutations might be left behind. Or perhaps the most successful treatments will target molecular mechanisms common to many cancers, making comprehensive genetic testing meaningless.

By its very nature, personalized medicine is difficult to assess. In the case of Janessa Laskin's patient, it is impossible to know whether the genomic information that guided her selection of drugs helped him live any longer than he would have otherwise. Scientists typically test new drugs and diagnostics by comparing the outcomes for patients who get these interventions and those who do not, but Laskin may never come across another patient with the same set of rare mutations.

By its very nature, personalized medicine is difficult to assess. Researchers and regulators will need to invent an entirely new way to evaluate treatment targeted at cancer patients whose genetic malfunctions may be unique.

Researchers and regulators will need to invent an entirely new way to evaluate treatments targeted at patients whose genetic malfunctions may be unique. "We're not measuring an individual gene or one specific algorithm," says Borisy. "We're asking the broader question of how this set of information supports physician decision making. That requires a different approach to clinical trials."

As an example, Borisy cites the small number of ovarian cancer patients who have mutations in the gene for EGFR, the same genetic mistake Meyerson linked to drug response in lung cancer several years ago. While several clinical trials have shown that specific drugs, known as EGFR inhibitors, work best in lung cancer patients with these mutations, similar trials would be impossible to conduct with ovarian cancer patients. "There are maybe only a thousand women in the U.S. in this situation. It would be decades before you could collect enough patients to have a typical clinical trial," he says. "But if you are the patient, you want access to this drug." tr

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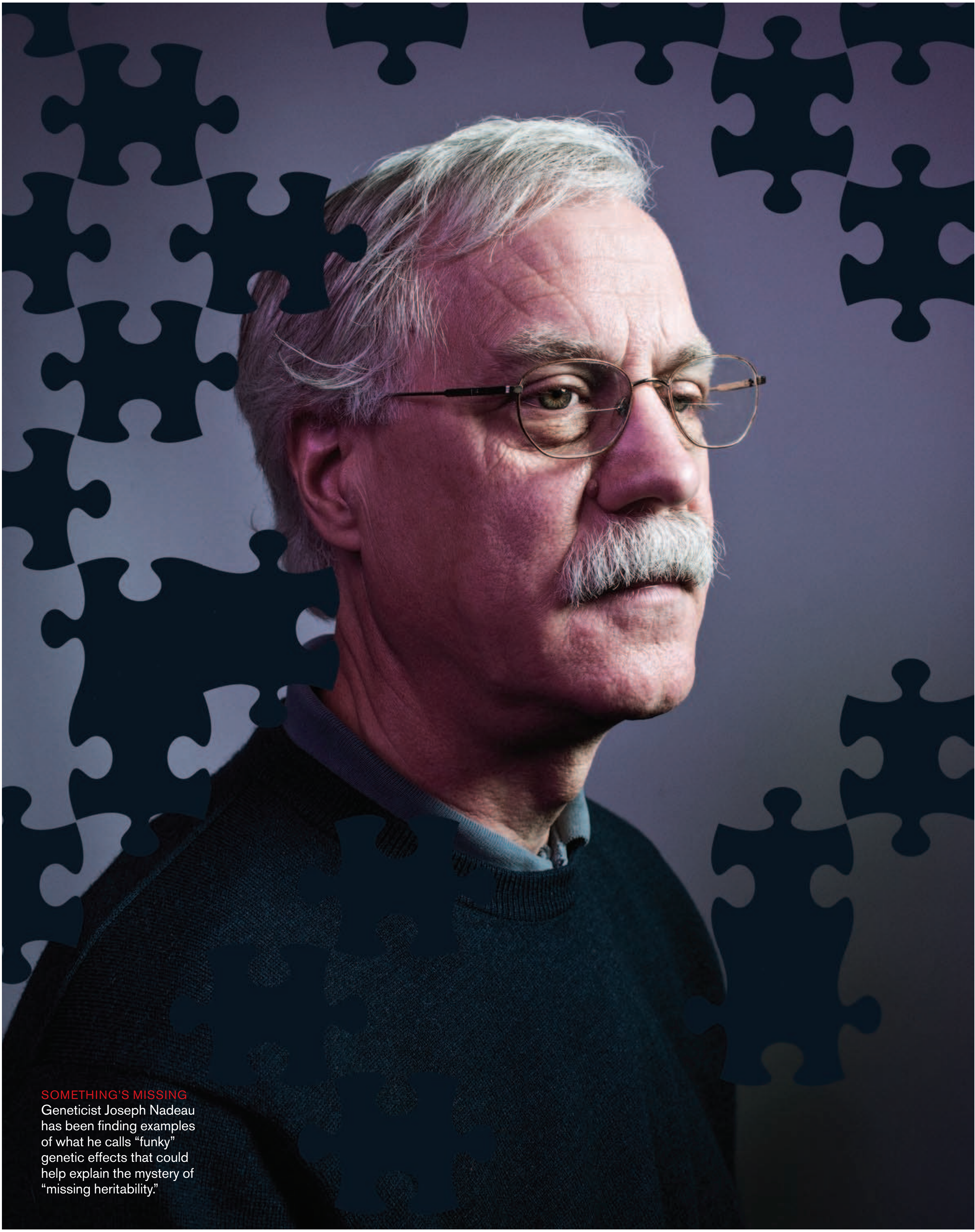

SOMETHING'S MISSING
Geneticist Joseph Nadeau has been finding examples of what he calls "funky" genetic effects that could help explain the mystery of "missing heritability."

The Genome's Dark Matter

Evidence is growing that your DNA sequence does not determine your entire genetic fate. Joseph Nadeau is trying to find out what accounts for the rest.

By STEPHEN S. HALL

What we know about the fundamental laws of inheritance began to take shape in a monastery garden in Moravia in the middle of the 19th century, when Gregor Mendel patiently cross-bred pea plants over the course of several years, separated the progeny according to their distinct traits, and figured out the mathematical foundations of modern genetics. Since the rediscovery of Mendel's work a century ago, the vocabulary of Mendelian inheritance—dominant genes, recessive genes, and ultimately our own era's notion of disease genes—has colored every biological conversation about genetics. The message boils down to a single premise: your unique mix of physiological traits and disease risks (collectively known as your phenotype) can be read in the precise sequence of chemical bases, or letters, in your DNA (your genotype).

But what if—except in the cases of some rare single-gene disorders like Tay-Sachs disease—the premise ignores a significant portion of inheritance? What if the DNA sequence of an individual explains only part of the story of his or her inherited diseases and traits, and we need to know the DNA sequences of parents and perhaps even grandparents to understand what is truly going on? Before the Human Genome Project and the era of widespread DNA sequencing, those questions would have seemed ridiculous to researchers convinced they knew better. But modern genomics has run into a Mendelian wall.

Large-scale genomic studies over the past five years or so have mainly failed to turn up common genes that play a major role in complex human maladies. More than three dozen specific genetic variants have been associated with type 2 diabetes, for example, but together, they have been found to explain about 10 percent of the disease's heritability—the proportion of variation in any given trait that can be explained by genetics rather than by environmental influences. Results have been similar for heart disease, schizophrenia, high blood pressure, and other common maladies: the mystery has become known as the "missing heritability" problem. Francis Collins, director of the National Institutes of Health, has sometimes made grudging reference to the "dark matter of the genome"—an analogy to the vast quantities of invisible mass in the universe that astrophysicists have inferred but have struggled for decades to find.

Photograph by JOHN KEATLEY

Joseph H. Nadeau has been on a quest to uncover mechanisms that might account for the missing components of heritability. And he is finding previously unsuspected modes of inheritance almost everywhere he looks.

Nadeau, who until recently was chair of genetics at Case Western Reserve University in Cleveland and is now director of research and academic affairs at the Institute for Systems Biology in Seattle, has done studies showing that certain traits in mice are influenced by specific stretches of variant DNA that appeared on their parents' or grandparents' chromosomes but do not appear on their own. "Transgenerational" genetics, as he calls these unusual patterns of inheritance, fit partly under the umbrella of traditional epigenetics—the idea that chemical changes wrought by environmental exposures and experiences can modify DNA in ways that either muffle a normally vocal gene or restore the voice of a gene that had been silenced. Researchers have begun to find that these changes are heritable even though they alter only the pattern of gene expression, not the actual genetic code. Yet it's both more disconcerting and more profound to suggest, as he does, that genes an ancestor carried but didn't pass down can influence traits and diseases in subsequent generations.

Consider the results of an experiment Nadeau and his colleague Vicki R. Nelson published last August. They created an inbred strain of mice and then compared two sets of females that were genetically identical except for one small difference: one set had a father whose Y chromosome came from another strain of mouse and contained a different set of genetic variants. That shouldn't have affected the daughter mice at all, because females don't inherit the Y chromosome. But the presence of that uninherited DNA in the previous generation exerted a profound effect on many of the more than 100 traits tested in the two sets of female offspring, whose own DNA was exactly the same. These results, Nelson and Nadeau concluded, suggest that "transgenerational genetic effects rival conventional genetics in frequency and strength."

In a separate but similarly unsettling line of experiments, Nadeau and his collaborators are finding that the impact of any given gene depends on all the other genes surrounding it. Nadeau is hardly the only scientist to identify these complex gene-gene interactions, but he and his colleagues have created a unique set of genetically engineered mice that is giving them and other scientists unprecedentedly precise tools for dissecting these "situational genetics" to show how the variants in a gene's molecular neighborhood affect the way it behaves.

Findings like these, taken together, could shed light on the missing-heritability problem, but at the cost of upending the dominance of traditional Mendelian ideas about how inheritance works. Sitting on the outside deck of the Institute for Systems Biology one recent afternoon, munching on a sandwich as seaplanes descended toward the skyline of Seattle, Nadeau recalled giving a talk about all this at a conference several years ago and discovering afterward that a prominent Ivy League geneticist in attendance, whom he declined to name, simply couldn't get the heretical ideas out of his head. "He came up to me after the talk," Nadeau recalled, "and said, 'This can't be true in humans.' I ran into him at breakfast the next day and he said, 'This can't be true in humans.' And then when the meeting was over, I ran into him at the airport, and he came up to me and said, 'This can't be true in humans.'" Or as another leading genome scientist once told Nadeau at a meeting in Europe, "If transgenerational effects happen in humans, we're screwed."

Gene-gene interactions could hold significant implications for medicine. Understanding the biology of protective genetic variants could offer new routes to disease prevention and treatment. The mechanisms could even lead to new drugs.

That is to say, discovering that his findings apply to humans would decouple a person's DNA sequence from her or his traits, calling into question much of the work scientists have done to find the genetic sources of complex diseases and develop drugs that target them. At a time when companies are analyzing customers' DNA for a fee, these ideas would make the results much more difficult to interpret medically and much more complicated to assess when trying to make a diagnosis or calculate disease risk.

Eric J. Topol, who heads genomic research at the Scripps Research Institute in La Jolla, California, agrees that genomics has suddenly gotten a lot more complicated. "There's a lot of non-Mendelian stuff going on," he says, "and there's a lot that we're going to have to sort out that doesn't have anything to do with the DNA sequence."

RUINING GENETICS

In 2009, a group of researchers based in the Netherlands published a stunning study on the genetics of human height—stunning because it failed to find much of a genetic component in one of the most obvious of inherited human traits. The group analyzed 54 recently identified genetic locations that statistical analysis sug-

suggested were the main contributors to height and discovered that all of them together accounted for only 4 to 6 percent of the height variance in thousands of subjects.

The "missing heritability" in the height study typifies many recent research reports in which large-scale genetic screens, known as genome-wide association studies, have identified a multitude of genes (or at least genetic neighborhoods) that are statistically associated with a biological trait like height or a disease like obesity, yet account for mystifyingly little of its propensity to run in families. What is interesting about Nadeau's findings is that even though they diminish the significance of single genes and the DNA sequences of individuals, the research preserves—and in some ways increases—the significance of family history, since even the genetic variants that parents and grandparents don't pass down through DNA seem to influence the traits of their children or grandchildren.

Nadeau, who is silver-haired and cheerful, has been investigating what he sometimes calls "funky" genetic results ever since sophisticated sequencing technologies became available about 10 years ago. Some of those results have been hinted at by traditional epigenetics, which has begun to trace changes that are transmitted from one generation to the next in animals even though the basic DNA sequence remains the same. (For example, researchers have found that rats whose cognitive performance was improved through environmental factors can pass those improvements down to offspring.) But where that field has typically focused on chemical modifications of DNA, Nadeau's work expands the notion of epigenetics to include genetic effects that may be transmitted by different molecular players: ribonucleic acids (or RNAs), which exert powerful regulatory effects on DNA.

Key evidence for Nadeau's general views on unconventional modes of inheritance grew out of a dissertation project that one of his students began around 2001. In the long tradition of misguided doctoral advice, everyone told Man-Yee Lam that her project was boring, derivative, and hardly worth doing; for five or six years, nothing in her results suggested otherwise. The focus of the project was testicular germ-cell tumors. It didn't become clear until much later that the experiment represented the first rigorous demonstration of a transgenerational effect, showing that genetic variations in a parent—even though they were not passed along to offspring—could dramatically change disease risks in those offspring.

Lam set out to see if she could identify interactions between several "modifier" genes—interactions that would increase susceptibility to testicular cancer in mice. She found lots of these interactions (some quite strong), completed her thesis, and graduated. Then, when the group started to write up the results for publication, they noticed something very peculiar: the effects had also occurred in some of the control animals bred from the same original population. In other words, males that had been bred so as not to inherit the disease mutations still had a statistically significant increase in their risk for testicular cancer, simply because the parents possessed a particular genetic variant. The results suggested that there could be patches of DNA in parents that affected the traits of children, even if the children did not inherit this bit of parental DNA.

Even before publication in 2007, Nadeau began describing the findings—to decidedly mixed reviews. He says, "If they were geneticists, there were all sorts of technical [objections] or 'It's not fair to talk about this in public. This is just too complicating, too—it's too *everything*!' One even said, 'Are you trying to ruin genetics?'"

"COMPLETELY CRAZY"

Nadeau isn't trying to ruin genetics, of course, but the other main focus of his research, involving gene-gene interactions in genetically engineered mice, also challenges the assumptions of modern Mendelians. Whereas conventional genomic studies assume that a number of individual genes contribute independently to complex diseases, Nadeau's group has been investigating how genes can work in concert to produce illness or, surprisingly, suppress it. Certain genetic variants neutralize other disease genes, so that a person's susceptibility to disease may depend more on the combined effect of all the genes in the background than on the disease genes in the foreground.

If this phenomenon is widespread, it holds significant implications for medicine. While enormous resources are routinely devoted to the search for disease genes, the research on gene-gene interactions—mostly in mice but increasingly in humans—suggests it may be at least as productive to identify protective and neutralizing genetic variants that counteract the effects of pathological variants. Understanding the biology of these protective variants could offer new routes to disease prevention and treatment. The mechanisms through which they exert their effects could even form the basis for new drugs.

To conduct his experiments, Nadeau and his collaborator, genomic pioneer Eric Lander, engineered 22 substrains of a commonly studied mouse strain called Black 6 by systematically replacing a different chromosome in each mouse with the corresponding chromosome from another strain, known as A/J. The idea of all this mixing and matching was to create a highly controlled system for studying gene-gene interactions, in part to determine how much a given gene contributes to the heritability of a disease or trait. By dropping in a "foreign" chromosome while holding everything else constant, the researchers could calculate the influence of each newly introduced gene. As Nadeau and his colleagues inserted one chromosome after another against the otherwise stable background and then measured the genetic effects, they discovered that the extent to which any gene affected the heritability of a given trait was dramatically larger than what more conventional genomic studies would have predicted. The

implication is that the potency—and, Nadeau would discover, the action—of disease genes must change with the context created by other genes on other chromosomes.

To illustrate how complicated this idea is, Nadeau hops out of his chair and rushes over to the whiteboard in his office, where he quickly sketches out how these "completely crazy" context-dependent effects can act even within a single chromosome. The experiments focus on a genetic variant they have identified on chromosome 6 in the A/J mice that completely protects the animal against obesity. When they drop the chromosome into Black 6 mice, they too are protected against obesity. But it's not that simple. When researchers stitch a bit of the DNA from the A/J strain into a large section of chromosome 6 in the Black 6 mice, the resulting mice are obese. When they trim away some of the Black 6 DNA and replace it with more A/J DNA, the resistance gene becomes active and the mice are lean. But when they add even more A/J DNA to this hybrid chromosome, the resistance gene turns off again. This on-off genetics continues even when the researchers add or subtract extremely small portions of chromosome 6. In fact, no matter how small the patch of DNA, nibbling away at it alternately confers and erases resistance to obesity. The reason is not known, but the larger message is that the effect of any variant seems to depend on its genetic surroundings. "We see that effect all the time," Nadeau says. "All the time! Everywhere, in every trait we look at."

Nadeau's group has also begun using these genetically engineered mice to explore transgenerational effects related to obesity. In research published several months ago, David Buchner, a researcher at Case Western Reserve, showed that one of the strains, which possesses a genetic variant that confers resistance to obesity, can pass this resistance to offspring that don't inherit the variant. The presence of the resistance gene in the paternal line of ancestry—either in the father or in the grandfather—was sufficient to inhibit diet-induced obesity and reduce appetite in mice that were otherwise genetically predisposed to getting fat.

HEALTHY GENES

Could humans also experience non-Mendelian forms of inheritance, particularly the complex gene-gene interplay that Nadeau keeps finding in mice?

Several years ago, Eric Topol launched a systematic attempt to study the genetics of elderly people who were in particularly good health. The researchers sought out subjects who met a series of stringent criteria: they had to be 80 or older, free of chronic diseases, and not taking any long-term medications.

Topol initially suspected a Mendelian explanation for their medical good fortune: he figured that they'd managed to avoid inheriting variant genes, or alleles, known to be associated with disease. Nadeau thought otherwise. He predicted, in fact, that people in the study would possess disease-related mutant genes like everyone else; what conferred their unusual health, he suspected, was the complex gene-gene interactions he'd seen in mice, where certain genetic variants in the background could neutralize the effects of pathological mutations. "The original premise—and Eric and I had a little bet on this—is that when they sequenced them, they would be free of disease-causing genes," Nadeau recalls. "My argument was, they've got the same load of disease-causing mutations as anybody else, but they also have variants that suppress those diseases."

Topol's results indicate that you can't gauge the impact of any given disease variant unless you know the identity of other variants in the background, including some that either modify disease genes or protect against them.

The study is still going on, and it turns out, as Nadeau predicted, that hundreds of the test subjects possess just as many disease-causing genes as members of the control group, which in this case consists of people who died more than a decade ago. According to conventional Mendelian genetics, people who harbor these "risk alleles" should be more susceptible to disease. And indeed, conventional genetic testing would point to a heightened risk for diseases they never developed. But Topol's results indicate that you can't gauge the impact of any given disease variant unless you know what other variants are in the background, potentially including some that either modify disease genes or protect against them. So Nadeau and Topol have advocated a systematic search for "modifier genes" and "protective alleles" that neutralize the deleterious effects of the disease-associated variants that everyone else has been looking for.

It may sound like a dramatic break, but Nadeau says these exceptions to Mendelian patterns should come as no surprise. "Mendel picked the traits where he would get simple genetics," he explains. "What Mendel said is true. But it's not the whole truth." tr

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Will Electric Vehicles Finally Succeed?

A new wave of plug-in hybrids and all-electric vehicles will have to overcome a familiar nemesis: battery costs.

By PETER FAIRLEY

At the end of 2010, GM and Nissan each began selling cars that run on electricity most or all the time. The Volt and the Leaf are only the first of dozens of new electric vehicles and plug-in hybrids to come: every major automaker has promised to start selling such cars over the next few years. Toyota, which has led the world in its development of gas-electric hybrid technology, plans next year to introduce a new version of its Prius that will be able to run on electricity alone for short distances. Meanwhile, startups such as Coda Automotive are trying to break into the auto industry with plug-in hybrids and all-electric cars—following the lead of Tesla Motors, whose electric sports car may have helped set the new wave in motion when it was introduced in 2006.

If these cars become popular with buyers, it will mark the beginning of the biggest shift the auto industry has seen for decades: a shift away from an almost exclusive reliance on petroleum and the internal-combustion engine. GM, just emerging from bankruptcy, is counting on the Volt to change its image from purveyor of the Hummer and other large SUVs to leader in innovation and energy efficiency. For its part, Nissan is staking much of its future on electric vehicles; over the next few years it plans to ramp up production to sell hundreds of thousands of them annually, far more than any other automaker.

The new cars are a departure from conventional hybrids, which use batteries mainly to supplement the gasoline engine and store

LEAF MEETS WORLD Nissan executives and guests give the automaker's all-electric car an enthusiastic introduction.

ASSOCIATED PRESS

energy recovered from braking. In those cars, the batteries are recharged by a generator that draws its energy not from a wall outlet but from either the gas engine or the regenerative brakes. Battery power alone can take them only short distances at low speeds. In contrast, the new generation of electric cars can run at least tens of miles without gas, and they can be recharged by plugging them in. Some, such as the Leaf, are totally dependent on the battery. Others, such as the Volt, use a combination of batteries and a gasoline engine. Each configuration has its own benefits and problems, but all are limited, ultimately, by one thing: despite many technological advances in recent years, the batteries remain expensive. The fate of the new electric cars will depend above all on automakers' ability to bring down battery cost, or find ways to engineer around it.

Take the Leaf. Its battery weighs 300 kilograms and is thought to cost as much as $18,000. Even at that considerable size and price, it gives the car a range of just 73 miles. That's enough for most commutes, but not for longer trips. And the range varies so much with weather and driving conditions that for many drivers

it will prove too short even for commuting. If you drive at a steady, low speed on a pleasantly warm day, you could go well over 100 miles. If you're stuck in traffic on a cold day using the heater, the Leaf might travel less than 60 miles on a charge.

The GM Volt has different problems. It can travel 35 miles on a charge and keep going for hundreds more using electricity generated by a gasoline engine. But pairing the battery pack with a gas engine and transmission is expensive. The car retails for $41,000—significantly more than the Leaf, which sells for around $32,780 and has a bigger battery pack. Meanwhile, Toyota's plug-in version of the Prius makes still other trade-offs. It costs thousands of dollars less to build than the Volt. But its electric motor is not designed for traveling much faster than 60 miles per hour without help from the gasoline engine, while the Volt's can hit 100 miles per hour. The most important difference is that the plug-in Prius has a much smaller battery pack. It stores just a third as much energy as the one in the Volt, so the car's electric range is comparatively short—just 13 or 14 miles. (Unlike the Leaf but like the Volt, the Prius has a gasoline engine, so it can keep going after its battery is depleted.)

HYBRID UPDATE A demonstration version of Toyota's new plug-in hybrid Prius tops off at a special charging station. The car can also be charged from an ordinary wall outlet.

It's not yet clear which strategy, if any, will yield electric vehicles that sell in high volume. Manufacturers haven't figured out which combination of price, range, and power consumers will prefer. Demand could also depend on how high gas prices rise and how worried the public gets about greenhouse-gas emissions and dependence on foreign oil. Yet despite such difficult-to-predict variables, it is almost certain that the most successful company will be the one that best understands battery technologies and the innovations that are likely over the next decade.

BATTERY BETS

Carlos Ghosn, the CEO of both Nissan and Renault and one of the biggest proponents of electric vehicles, is betting that manufacturing large numbers of them will lower the cost of batteries enough to make all-electric vehicles competitive with conventional ones. One million cars, says Ghosn, is the point at which the production volume will make batteries affordable, and he hopes to approach that total fairly soon. Nissan and Renault will have global capacity to produce 200,000 electric vehicles by 2012 and half a million by 2014, he predicts.

Automakers don't disclose exactly how much they're paying for batteries, but independent studies suggest that the cost is between $600 and $850 per kilowatt-hour. To make the Leaf profitable, Nissan representatives have said, the company plans to push battery costs down to $370 per kilowatt-hour—a level that many experts predict isn't achievable for a decade, though Nissan seems confident of hitting it sooner. To give the Leaf a range that's more competitive with that of a gasoline vehicle—say, 300 miles—battery costs would have to come down much more, since the car would need batteries about four times as big as those in the current car. It will take equally aggressive cost reductions to make plug-in hybrids such as the Volt economically viable, according to the U.S. Department of Energy. It estimates that plug-in hybrids with a range of 40 miles won't be cost-competitive with conventional cars, even when fuel savings are taken into account, until battery costs drop to between $168 and $280 per kilowatt-hour.

Despite Ghosn's expectations, merely increasing the volume of battery production may not bring prices low enough. The new electric vehicles and plug-in hybrids use lithium-ion batteries, which are more compact and lightweight than the nickel–metal hydride batteries used in previous electric cars and in the conventional hybrid Prius. Many battery experts, including some at GM, argue that high-volume production of lithium-ion batteries for use in laptops and mobile phones has already squeezed out much of the excess cost. What's more, increasing production enough to meet the needs of the auto industry could drive up the cost of battery materials such as manganese, at least in the short term.

If increasing production volume doesn't do the trick, the remaining hope is innovation. New kinds of batteries that use cheaper materials and store more energy could greatly reduce costs, mainly by decreasing the number of cells needed to power a car. Researchers are developing several battery technologies in laboratories around the world. Nanostructured silicon electrodes have been used to make prototype batteries that store twice as much energy as conventional lithium-ion batteries. Solid-state batteries replace liquid electrolytes with solid ones that are more

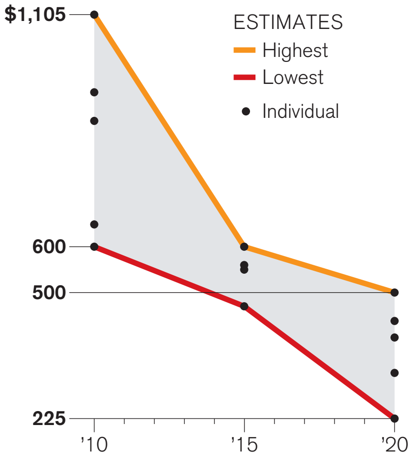
TOYOTA

THE PRICE OF BATTERIES

Although costs are uncertain, they will be key to the success of electric cars.

Expert guesses at present and future battery costs vary widely.

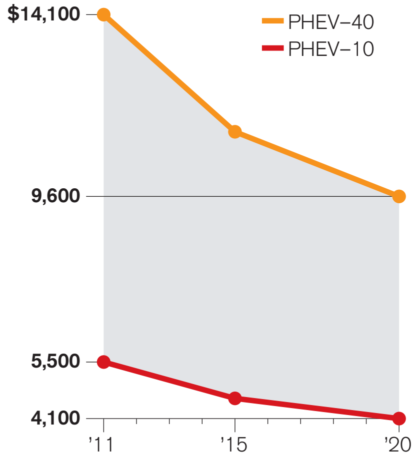
Estimates of electric-vehicle battery costs
$ per kilowatt-hour



Sources: Advanced Automotive Batteries, Boston Consulting Group, Deutsche Bank, Electrification Coalition, National Research Council, and Pike Research

Plug-in hybrids with modest electric range will remain far more affordable than those that go farther on a charge.

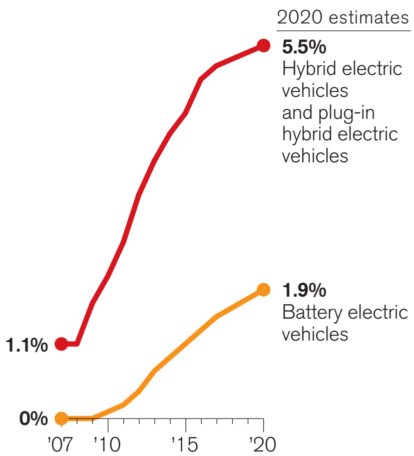
Additional cost of a plug-in hybrid electric vehicle (PHEV) over a conventional vehicle*



*Note: *Low estimates for cars with 40- or 10-mile electric range. Source: National Research Council*

The share of battery-powered vehicles will grow but will remain small through 2020, largely because of high costs.

Market share of hybrid and electric vehicles
2007–2020, estimated



Source: J. D. Power & Associates

The size of the battery packs greatly influences the price of new electric cars and plug-in hybrids. The range automakers expect to get per kilowatt-hour varies because of differences in vehicle weight, expectations about driving patterns, and capacity kept in reserve to hedge against battery deterioration.

Important new plug-in hybrids and all-electric vehicles

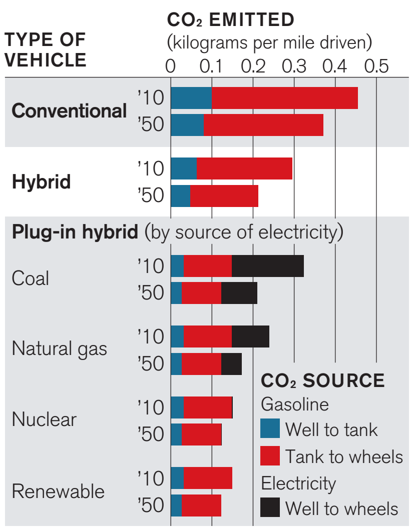
MAKE/ MODEL	TYPE*	ESTIMATED PRODUCTION DATE	TOTAL ELECTRIC RANGE (miles)	BATTERY CAPACITY (kWh)	PROJECTED PRICE
Chevrolet Volt	PHEV	In production	35	16	$41,000
Mitsubishi iMiEV	EV	In production	80	16	$40,000
Nissan Leaf	EV	In production	73	24	$32,780
Aptera 2e	EV	2011	20	21	$25,000–$45,000
BYD e6	EV	2011	250	48 or 72	$650/mo. lease
Ford Focus	EV	2011	100	23	N/A
Smart ED	EV	2012	85	16.5	N/A
Tesla Model S	EV	2012	160/230/300	42/65/85	$56,500 and up
Toyota Prius	PHEV	2012	13	5.2	N/A
Volvo C30	EV	2012	90	24	N/A

*Notes (vehicles table): *EV= electric vehicle (battery), PHEV= plug-in hybrid electric vehicle*
Sources: Sentech and manufacturers

Notes (emissions chart): Coal figures are based on highest-emitting coal plants in 2010; natural-gas figures are based on new combined cycle plants in 2010. Source: Electric Power Research Institute, 2007

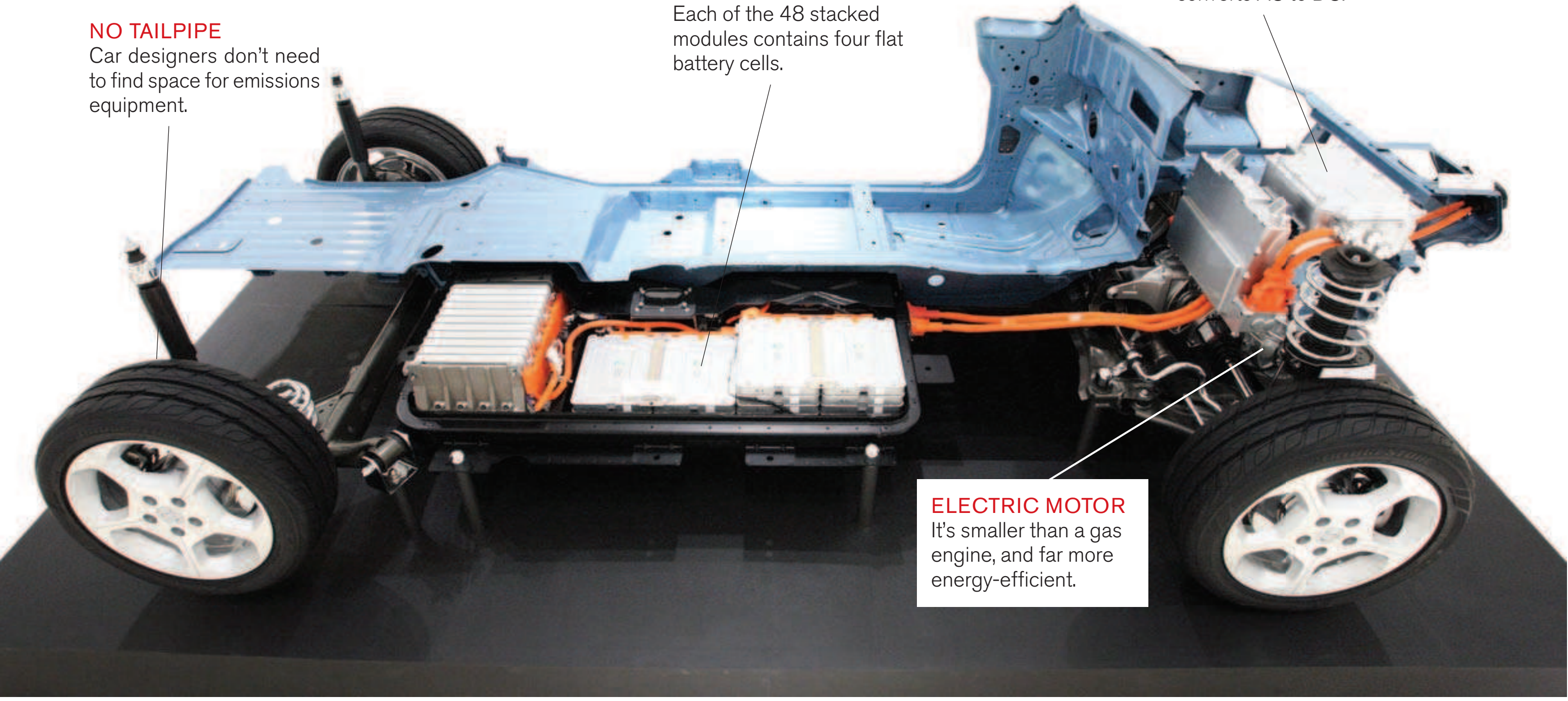
High costs could promote small battery packs, which would help limit carbon dioxide emissions. Today, hybrids emit less than plug-ins in most places.

Greenhouse-gas emissions



TOMMY McCALL

INSIDE THE LEAF



compact and less flammable, reducing the need for bulky cooling systems. Another new type of battery, called metal-air, could in theory allow cars to travel 500 miles on a charge, according to the Department of Energy.

Although there's hope on the horizon, it will take years—in some cases decades—before batteries that look promising in the lab can be installed in production cars. Even if a given battery technology has been used in devices such as mobile phones, qualifying it for the much more demanding environment of automobiles is no easy task. Automakers expect batteries to last at least eight to 10 years without losing more than about 30 percent of their storage capacity. And the batteries must work well not just at room temperature but in the extreme cold of the northern United States and Canada and in the extreme heat of places like Arizona, Nevada, and Southern California. Engineering batteries to withstand these conditions, and the continuous vibration and jolting they have to endure on the road, can take several years. Confirming that the batteries make the grade can take even longer.

Andrew Burke, an expert on electric-vehicle batteries at the University of California, Davis, says that novel lithium battery chemistries are "way in the future"—probably well over a decade off. If he's right, using smaller batteries, even if that limits electric range, is the best way to move forward with plug-in vehicles while keeping costs low enough for most consumers. As Dan Santini, a senior economist in at the U.S. Department of Energy's Argonne National Laboratory, puts it: "The costs imply you should make a shorter-range vehicle. That's the safer way to go."

REPEATING HISTORY?

The last time major automakers made a big push for electric cars was a little over a decade ago, when GM unveiled its EV1 and Toyota released its electric RAV4 SUV in response to a California mandate on zero-emissions vehicles. Over five years, starting in 1998, Toyota sold or leased just 1,484 of the RAV4s, a dismal showing that was due at least in part to the cost and range limitations of the batteries. The RAV4 cost $42,500 and had a range of around 100 miles.

At about the same time those electric vehicles came out, Toyota started selling its hybrid Prius. It sold for less than half the price of the electric RAV4 and didn't have its range limitations. The Prius represented a breakthrough in engineering, elegantly solving the problem of how to blend power from an electric motor and a gasoline engine. Since its introduction, in 1997, it has sold in the millions. To this day, Toyota dominates the hybrid market, selling three times as many vehicles as its nearest competitor.

This time around, has Toyota fallen behind in innovation or has it again outwitted its competitors? Its car is coming relatively late, and it has a much shorter electric range than the Volt or the Leaf. But the decision to use a small battery could prove smart. For drivers who have short commutes, the advantages of the plug-in Prius are obvious. Dragan Maksimovic, a professor of electrical, computer, and energy engineering at the University of Colorado, used a test model of the car for his daily 18-to-20-mile trip across Boulder and for a weekend drive to the mountains. In these test drives, he recorded overall fuel efficiency of 92.3 miles per gallon—81 percent better than the mileage of the conventional Prius.

NISSAN

Argonne researchers who analyzed the potential impact of plug-in hybrids on gas consumption nationwide found that while big batteries and longer range yield bigger fuel savings, the cost is disproportionately high. With a vehicle like the plug-in Prius, roughly 25 percent of miles traveled by car in the United States could be powered by electricity. For cars with a 40-mile electric range, that number jumps to 32 percent—promising about one-third more potential fuel savings. But the batteries could cost three times as much.

All-electric vehicles like the Leaf, the researchers argue, will have little impact on fuel consumption because relatively few of them will be sold: consumers will want gasoline backup for longer trips. "The all-electric vehicle has a limited niche and thus a limited ability to save fuel compared to the plug-in hybrid," Santini says. "The plug-in hybrid with a 20-mile range will be a better bet than the one with 40. A very large fraction of the United States' population can cost-effectively use these vehicles."

If manufacturers can make their case to that chunk of the public, sales of cars with limited electric range could surge, says Lew Fulton, a senior transport energy specialist at the International Energy Agency in Paris. Toyota, with its lead in hybrid technology, could do especially well. "There's going to be a big pile of other manufacturers who are cursing in about three years or so," Fulton says. "Toyota's going to come out smelling like roses."

Whether his prediction proves correct will depend on a number of things. Drivers might be willing to pay more for longer range than researchers at Argonne assume. That would favor the Volt. The market for all-electric cars might be bigger than it was a decade ago—20,000 people have put down $100 deposits on the Leaf, enough potential customers to overwhelm the sales figures for the EV1 and the electric RAV4. Government subsidies could also shift the balance: in the United States, a federal tax credit program gives bigger rebates for plug-in hybrid and electric cars with larger battery packs, shrinking the price difference consumers will see. (The credits will be phased out after the 200,000th car sold by a manufacturer.) Finally, battery costs could come down faster than expected. The Department of Energy is pouring billions into new U.S. battery plants and hundreds of millions into research and development.

Yet with all the uncertainty, the best strategy could be the one that's the most flexible. And here is where Toyota's approach might really pay off. If batteries become cheaper, Toyota could expand the battery pack in its plug-in Prius to increase the vehicle's electric range. And it could adapt the technology to the six new hybrid models it plans to introduce in 2012.

"They all could be plug-ins," says Justin Ward, manager of the advanced power train program at Toyota's technical center in Pasadena, California. "Whether that makes sense or not, the market will decide." And so, he might add, will the batteries. tr

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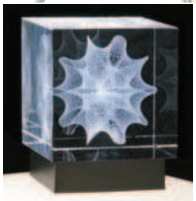


BRIEFING
The Smart Grid

INTRODUCTION

Smart meters must be backed up by new transmission infrastructure

TURBULENCE AHEAD Without systematic upgrades to electrical grids, it will be difficult to integrate large amounts of power from intermittent renewable sources such as the wind and sun.

RICHARD CUMMINS/CORBIS

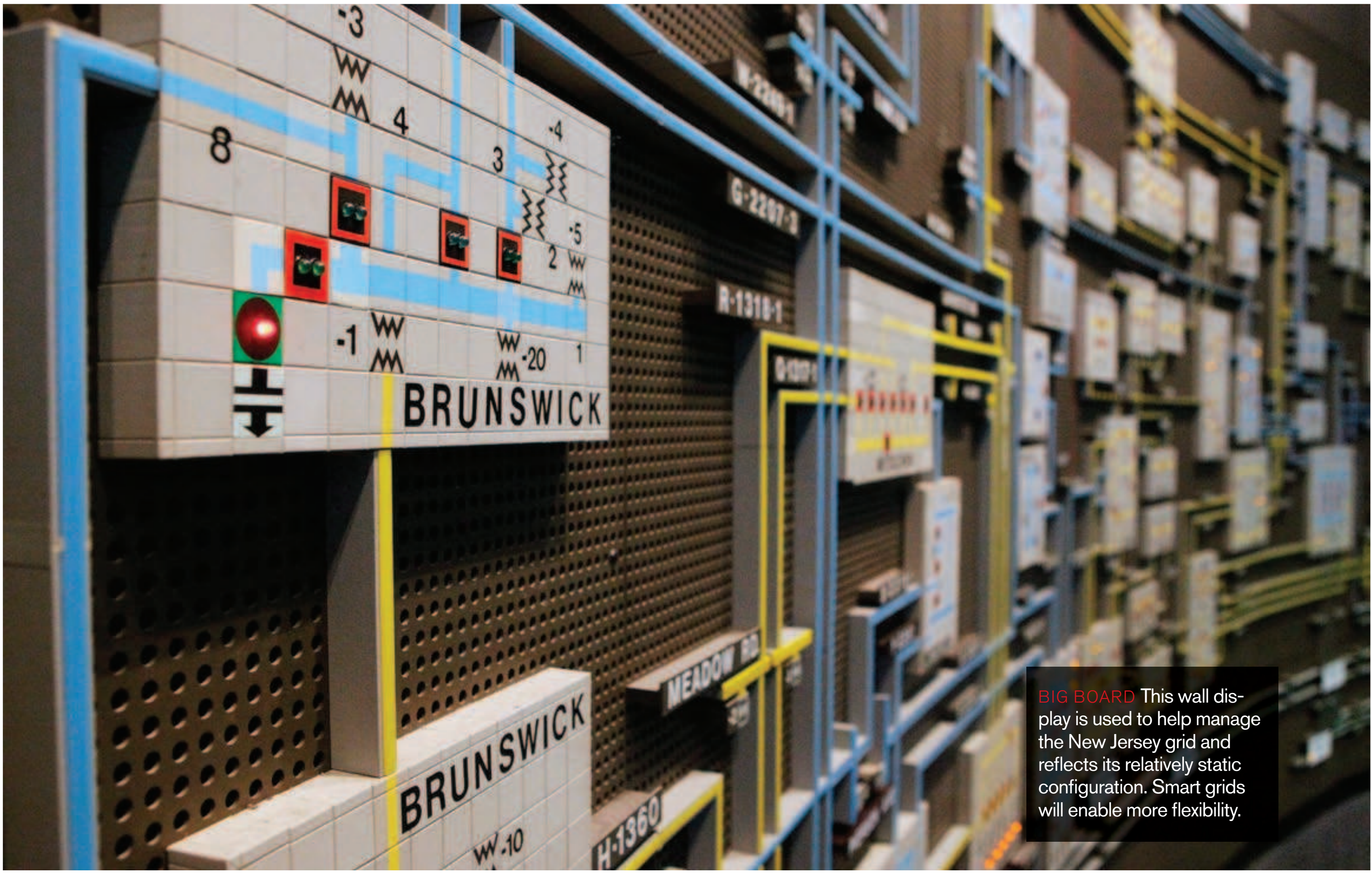
Electrical grids, the interconnected systems that transmit and distribute power, are at the heart of how we use energy. Yet despite their importance, in many places around the world these grids are falling apart. In the United States, while electricity demand increased by about 25 percent between 1990 and 1999, construction of transmission infrastructure decreased by 30 percent. Since then, annual investment in transmission has increased again, but much of the grid remains antiquated and overloaded.

Aging grids mean an unreliable electricity supply. They are also an obstacle to the use of renewable power sources such as wind and solar. It is estimated that generating electricity creates 11.4 billion tons of carbon emissions worldwide each year—nearly 40 percent of all energy-related carbon emissions. Renewable sources could reduce those emissions, but grids that were designed for a steady flow of power from fossil-fuel and nuclear plants have trouble dealing with the variable nature of wind and solar power.

Smart-grid technology aims to put control and monitoring devices throughout the grid, tying them together with new communications systems. This will increase the grid's stability, making it easier to integrate renewables *(see "Managing Renewables," p. 66.)*

Smart-grid demonstration projects are under way around the world, the most visible aspect of which has been the installation of smart meters in homes and businesses. By giving customers a financial incentive to limit their usage at peak times, smart meters can lessen demands on the grid. But without new transmission and generation infrastructure to go along with these meters, the smart grid will fall short of its promise to curb our appetite for fossil fuels and increase the reliability of the electricity supply.

Making these infrastructure improvements is proving difficult *(see "Paying the Utility Bill," p. 67),* in large part because of the staggering expense—hundreds of billions of dollars will be needed worldwide. But the cost of not upgrading will be even steeper. —*Stephen Cass*



BIG BOARD This wall display is used to help manage the New Jersey grid and reflects its relatively static configuration. Smart grids will enable more flexibility.

ARISTIDE ECONOMOPOULOS/STAR LEDGER/CORBIS

TECHNOLOGY OVERVIEW

Managing Renewables

Creating smart grids will require new technologies along the entire chain of electricity generation, distribution, and consumption. These systems will let operators know exactly how electricity is flowing through the grid from moment to moment, and they will make it possible to control that flow quickly and precisely.

At the heart of smart grids is communication. Grid operators are moving toward Internet-based protocols that can rapidly exchange information between many locations. Faster communication is crucial for one of the most important new technologies: units that measure, many times per second, the waveform of the alternating current flowing through the line. Changing waveforms can alert operators to problems on the grid; the information is relayed back to centralized control units and then to utilities. This technology represents a huge step forward from the old system, in which it's not unusual for a utility to be unaware of a transmission problem until a customer calls to complain that the power is out.

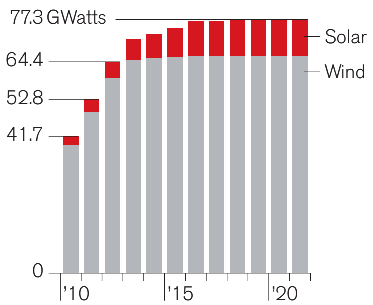
Control over the grid has also been improved by new and upgraded supervisory control centers and data acquisition centers. These centers have relied on the telephone network to communicate with substations, but new systems use Ethernet-based networks or other modern technologies. Information gathered from all over a local transmission network makes it possible to respond to problems—a downed power line or a lightning strike—within fractions of a second.

Being able to control the flow of electricity in close to real time is essential if unpredictable energy sources, such as solar and wind, are to provide a significant fraction of our electricity. Left unchecked, a sudden variation

WINDY FORECAST

Grids will need to absorb sharply increased amounts of renewable power.

U.S. wind and solar power capacity



Source: EIA

in power output from, say, a wind farm could destabilize a grid. Today, grids can absorb such fluctuations because wind is responsible for only a small amount of power—about 2 percent of electricity generated in the United States. But once wind power accounts for a significant percentage of electricity, we'll need a better way to manage the grid.

Besides large-scale energy storage technologies *(see "Better Storage," p. 69)*, another thing that could makes renewable sources more manageable is an existing technology called flexible AC transmission systems, or FACTS. These systems generally use semiconductor components specifically designed to handle high voltage and current in a way that stabilizes power flow. They can be added to substations or set up as stand-alone units where a wind or solar installation connects to the grid. —*Dave Levitan*

DATA POINT

76 million

The number of smart meters in use worldwide in 2009. The projected number of smart meters to be deployed by 2014: 212 million.

CHARTS BY TOMMY McCALL

INDUSTRY CHALLENGES

Paying the Utility Bill

Utilities around the world are busy installing smart meters that will tell customers the price of the electricity they use throughout the day. Appliance manufacturers are building refrigerators, washing machines, and air conditioners that can automatically go into low- or no-power mode when demand spikes. Renewable-energy companies are selling solar, wind, and even geothermal power to the grid. But all this activity will not significantly improve the reliability of grids, or curb the appetite for coal-fired power plants, unless it is accompanied by major improvements in the infrastructure used to generate and transmit electricity.

Around the world, obsolete and overloaded transmission networks are the norm. In the United States, power supply problems such as outages and voltage sags cost businesses more than $100 billion a year, and the threat remains of another massive blackout, like the one that affected more than 50 million North Americans in 2003. But despite near-unanimous agreement that the infrastructure needs to be improved, little progress has been made.

One problem is that building grid infrastructure often requires permits that, largely because of local opposition, are difficult and costly to obtain. An April 2010 report on smart grids by the EU-supported European Electricity Grid Initiative lists public opposition to grid improvements as one of the biggest obstacles to progress. In the United States, a transmission line intended to bring solar, wind, and geothermal power to San Diego from the California desert was delayed for years by litigation and protests. Construction finally began a few months ago.

An even bigger problem is that upgrading grid infrastructure is expensive. For example, in the northwestern United States, the Bonneville Power Administration, a federal agency that generates and sells hydroelectric power, is adding more than 350 kilometers of transmission lines to the grid at a cost of about $1 billion, or roughly $2.8 million per kilometer. The Bonneville project received federal funding, but generally it's difficult to find money to build new infrastructure. In China, among other countries, utilities are state-owned, so the money must come from government budgets. The EU is developing a scheme in which subsidies for smart-grid upgrades will be funneled to one centralized organization. But in much of the rest of the world, the majority of the infrastructure for generating and transmitting electricity belongs to investor-owned utility compa-

FEEDING THE METER

Governments have pumped billions into grid projects, but even more will be needed.

Federal stimulus investments by country
(in millions of dollars, 2010)

*Note: *Does not include $6.5 billion in increased borrowing authority. Source: Zpyrme*

nies that have little economic incentive to invest billions in infrastructure.

China, where a significant portion of the grid is only now being built up for the first time, spent more than $7.3 billion of government funds on its smart grid in 2010. The United States has also made considerable federal investment in upgrades, with $4.5 billion in 2009 stimulus funding allocated specifically to developing smart-grid technologies and $6.5 billion in increased borrowing authority for power agencies in the Northwest to build new transmission lines. But these figures are still just a fraction of the total required: a 2004 estimate by the industry-funded Electric Power Research Institute pegged the cost of upgrading the U.S. grid at $165 billion over 20 years, and the figure is still considered accurate.

With so much uncertainty, is there any new business model that would compel utilities to spend billions on the smart grid? "That's the million-dollar question," says Steve Hauser, of the U.S. National Renewable Energy Laboratory. "I'm not sure that anyone has an answer to that."

—Dave Levitan

DATA POINT

20 terawatt-hours

Global electricity generation in 2008; 68 percent of this electricity was produced by burning fossil fuels.

PROJECTS TO WATCH

Demonstrations and Upgrades

Project	Cost	
Miyakojima Island Smart Grid, Japan (Okinawa Electric Power)	$75.8 million	Using a small island as a test bed, a Japanese consortium is developing systems for renewable power generation, grid integration, and energy storage.
Pacific Northwest Smart Grid Demonstration Project, United States (Battelle and Bonneville Power Administration)	$178 million	Involving 60,000 consumers spread over five states, this project will test every element of a smart grid.
HVDC transmission network, China (State Grid Corporation of China)	Not available	High-voltage DC transmission lines are being built to transfer energy from remote hydropower plants to cities more efficiently than is possible with traditional AC systems. The Chinese are building some of the world's highest-voltage DC systems (up to 1,000 kilovolts) over distances well over 1,000 kilometers.
Twenties (European Union)	$75 million	The consortium is deploying six demonstration projects over three years to show how wind power can be integrated with the grid.
Community Power Project, Arizona (Arizona Public Service Company)	$3.3 million	Enough solar panels to generate 1.5 megawatts are being installed to see if the grid can cope with hundreds of distributed generation sites and the variability of solar power.

OVER THE HORIZON

Everything Is the Grid

Smart grids alone could help curb the need for additional power plants and decrease carbon emissions. But they'll do even more good where they can be combined with new heating and transportation systems, whether that's on the scale of an individual building or of an entire city.

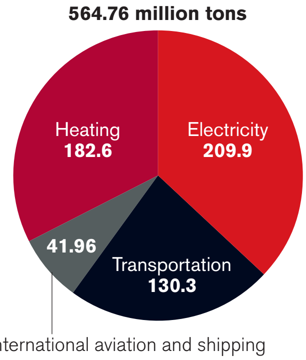
"In most places we've got completely separate power, heat, and transport systems," says David Clarke, CEO of the U.K.'s Energy Technologies Institute, an organization jointly funded by industry and the British government. Because power generation appears to be the easiest energy system to "decarbonize," Clarke foresees that nearly all heating and transportation will eventually be brought under the electrical umbrella, through technologies such as electric vehicles and residential heat pumps that use the air or ground as a heat source or sink.

Before that all-electric future arrives, Japan

ENERGY SECTORS

A 2050 U.K. CO_2 emissions target of 125 million tons demands a combined energy strategy.

U.K. annual CO_2 energy emissions (in millions of tons, 2008)



Source: Energy Technologies Institute

is testing other technologies to reduce urban energy demand by better integrating power and heating systems. It is spending a billion dollars in four cities over five years to develop and deploy technologies such as residential natural-gas fuel cells: the cells reduce the amount of power the grid must supply, while waste heat from the fuel cell is used to warm the house. When electricity and heat are both generated on-site in this way, a house requires less total energy than it would if warmed and powered separately. *—Stephen Cass*

RESEARCH TO WATCH

Better Storage

Electricity, unlike fuel, cannot be stockpiled. For the most part, it must be created at almost the instant it is consumed. This means that generating plants must be able to accommodate the largest possible spike in demand, even if such a spike occurs only once or twice a year. And much electrical energy goes to waste, as when wind farms are taken offline because they are producing more electricity than is needed.

SMOOTHING THE FLOW This sodium-sulfur battery, developed by Xcel Energy, can store 7.2 megawatt-hours of electricity and is designed to compensate for wind power fluctuations.

ELECTRICITY STORAGE ASSOCIATION

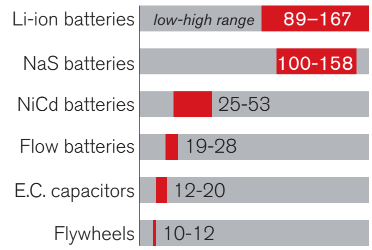
Industrial and academic researchers are trying to solve these problems with new large-scale energy storage technologies. Notable contenders include scaled-up lithium-ion batteries and liquid metal batteries. To date, lithium batteries have been relatively expensive and short-lived. To try to overcome these drawbacks, startup Seeo *(see TR35, September/October 2010)* is replacing the batteries' usual liquid electrolyte with solid polymers. As well as lasting longer, solid polymers allow the batteries to store more energy, giving more bang for the buck.

Liquid metal batteries, developed at MIT *(see TR35, September/October 2010)*, employ a liquid electrolyte made from metals such as magnesium and antimony. They are heated to 700 °C to keep the electrolyte molten. The result is a battery that can handle the very high current that utility-scale storage entails. *—Kirsten Korosec*

POWER RATINGS

Low-density technologies store less energy by weight but can be cheaper or charge faster.

Energy density of storage technologies
(kilowatt-hours per ton)



Source: Energy Storage Association

CASE STUDY

Gluing the Grid Together

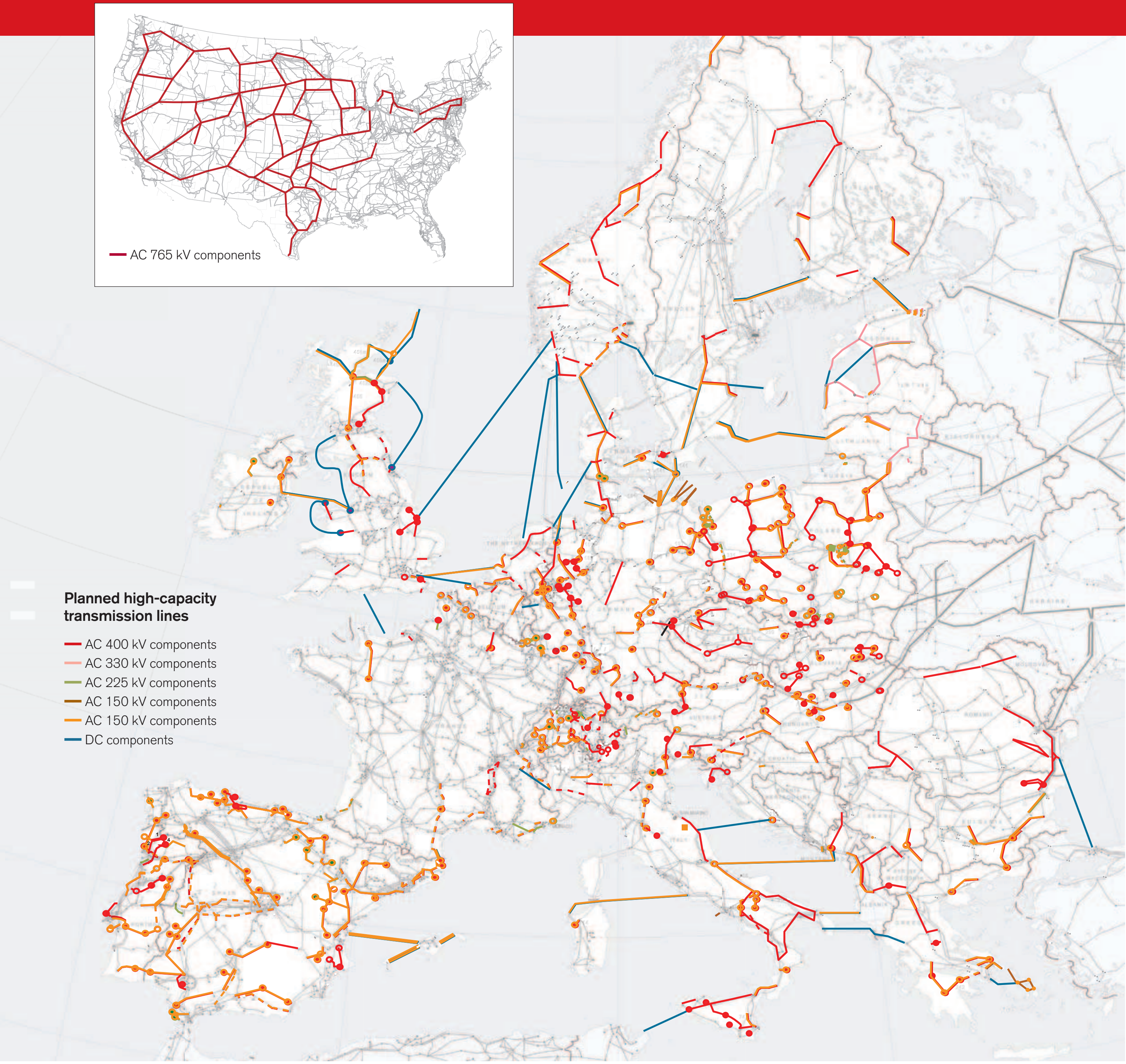
Silver Spring Networks, one of the earliest smart-grid companies, was founded in 2002 by software engineers who saw a need for standardized technology that would enable systems throughout the grid to communicate with each other. "You want a secure network infrastructure that can be connected to an arbitrary number of devices—thermostats, displays, electric vehicles, anything that plugs into the grid," says Silver Spring's chief technology officer, Raj Vaswani.

So the company developed devices, services, and software to help monitor and manage energy supply and use for both consumers and utilities. Today, its products can be found in a number of projects in the United States and Australia. Oklahoma Gas and Electric, for example, has built its communication chips into smart meters and uses its software to read them. Consumers can monitor their energy use by way of a Web portal that Silver Spring provides. The utility now manages demand so much better that it has been able to shelve plans for two new power plants, which would have cost up to $320 million.

Silver Spring raised $100 million in venture capital in December 2009, bringing its total funding to around $250 million. And it has been broadening its scope beyond meter networking and into software, which has a higher profit margin. This expansion has the potential to cause problems. "There's a risk that they are growing faster than they can support," says Steven Minnihan, an analyst at Lux Research.

But failing to grow would be risky as well. Heavyweights like GE and Cisco are entering the smart-grid market with the advantages of name recognition and, in the case of GE, an already established foothold in the global energy market. Vaswani, however, describes the business scenario for Silver Spring as one of "coöpetition" rather than competition. Fixing the grid will take a great deal of infrastructure, he says: "No one company is going to be able to build all of it." He adds that Silver Spring and GE already do a lot of business together as partners.

—Katherine Bourzac



MAP

Joining the Dots

Assembled piecemeal over the last 100 years or so, power-grid networks now span entire continents, with regional distribution grids stitched together through interconnects. Improving the ability of operators to balance variations in supply and demand will require the construction of new high-capacity transmission lines to share power over larger areas. Because Europe has a more uniform population density than the United States, fewer long-distance lines are required. In the United States, these lines are necessary to transfer renewable power from the windy heartland and sunny Southwest to the heavily populated coasts. —*Stephen Cass*

CHARGE 'ER UP A public recharging station for electric and plug-in vehicles in London. Managing electric vehicles so that they don't stress the electric grid will require new software.

NANCY HONEY/CULTURA/CORBIS

MARKET WATCH

Utility Market Opens to New Competitors

Innovation in distributing electricity has traditionally been the preserve of corporate behemoths like General Electric and Siemens, which sell equipment to utilities. But smart-grid technology has allowed IT companies and startups to enter the market.

Currently, most smart-grid money is going toward the rollout of systems that connect smart meters in consumers' homes to utilities by means of various communication technologies. But by 2015, the smart-meter market will peak at $5 billion, according to Bob Gohn of the clean-technology analysis firm Pike Research, and utility capital expenditures will be aimed at automating distribution, using technologies that improve the flow of power through the transmission network (*see "Managing Renewables," p. 66*).

In the distribution automation sector, established firms such as GE, ABB, Schneider Electric, and Siemens are finding themselves competing against new players, including large IT firms like Cisco and IBM and telecom companies like AT&T and Verizon. The new entrants are attracted to the smart grid because energy is one of the last sectors to incorporate IT and they see a new opportunity to profit from their technology and customer bases.

Cisco has made a particularly aggressive entry into the smart grid, moving to compete in nearly every subsector—including advanced metering networks, distribution automation, data storage, and even home energy management. In the past year, Cisco has purchased the wireless network startup Arch Rock and partnered with Itron to work on a grid communication platform based on Internet standards. Cisco is developing an Internet-protocol-based communication system for Duke Energy's $1 billion smart-grid infrastructure project, which will connect the utility to four million customers in a five-state service area. And it has developed a touch-screen-based system that can connect with smart appliances to let residential customers manage their energy use.

Startups, which in the past found it difficult enter the utility grid market because of high capital costs, have discovered exploitable niches in smart-grid technology. Among those attracting venture capital are GridPoint and Silver Spring Networks (*see "Gluing the Grid Together," p. 69*), which have partnered with utilities to deploy new energy management systems, and Tendril, AlertMe, and EnergyHub, which are developing home area networks that enable appliances and smart-grid devices to communicate. The coming wave of plug-in hybrids and all-electric vehicles should create additional opportunities (*see "Everything Is the Grid," p. 68*), such as developing software to optimize the schedule on which cars are recharged.

—Kirsten Korosec

DATA POINT

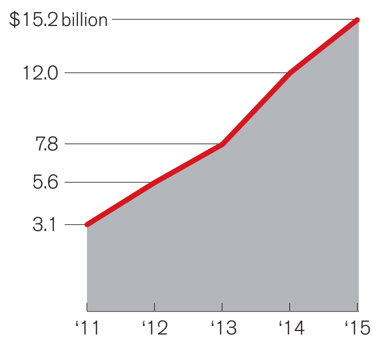
42,100 km

Total length of new and upgraded power lines that will be installed in Europe over the next 10 years.

HOME FRONT

Soon, appliances such as refrigerators and air conditioners will network with smart meters.

Global smart-appliance market
(in billions of dollars, 2010)



Source: Zpryme

THE BIG PICTURE

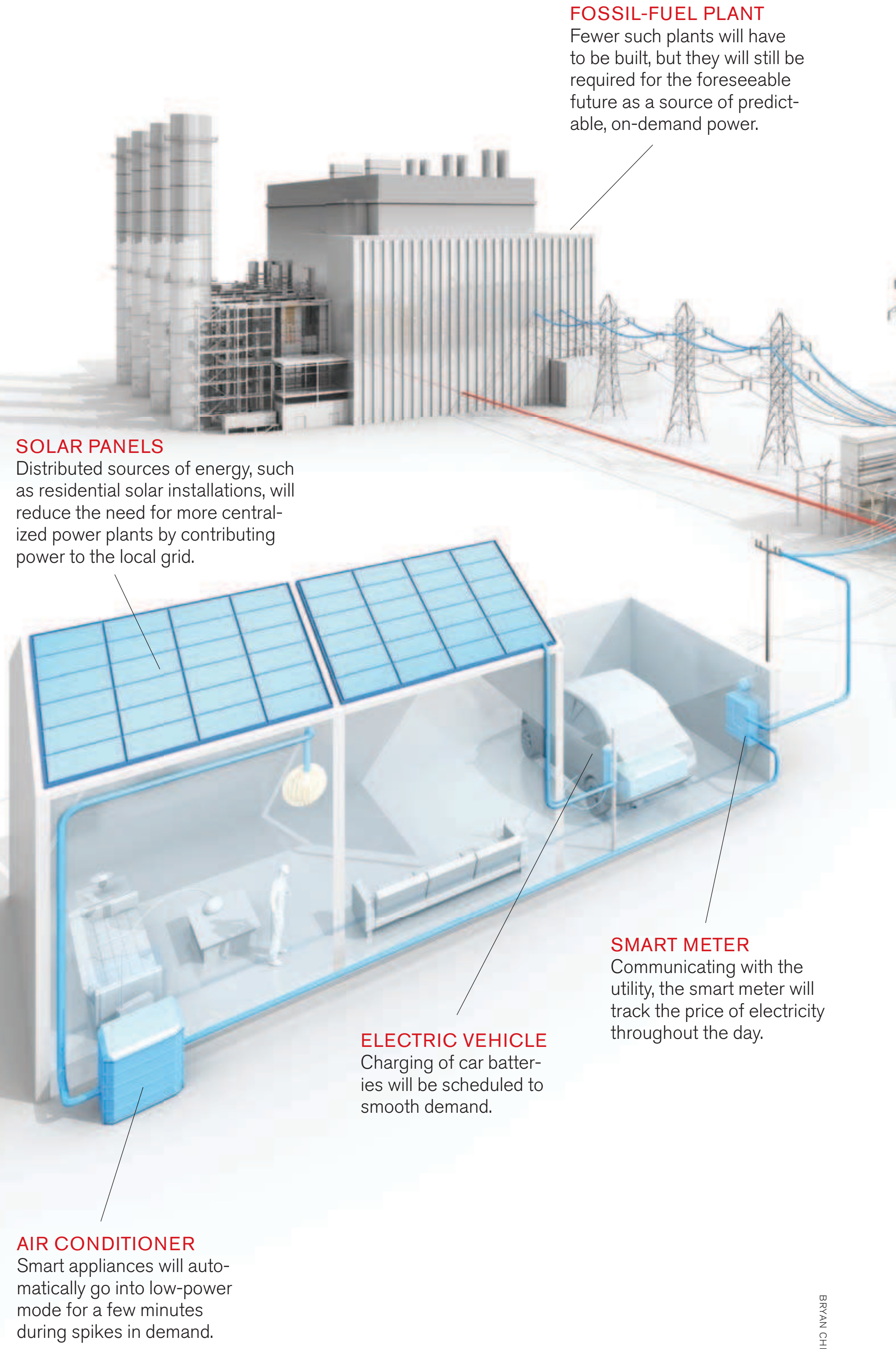
Power Control

Smart grids use communication technologies (red lines) to tie together the transmission network (blue lines), power sources, and control systems. This reduces the need for additional power plants, allows renewable energy to replace fossil-fuel power plants, and makes the grid more resistant to blackouts and brownouts.

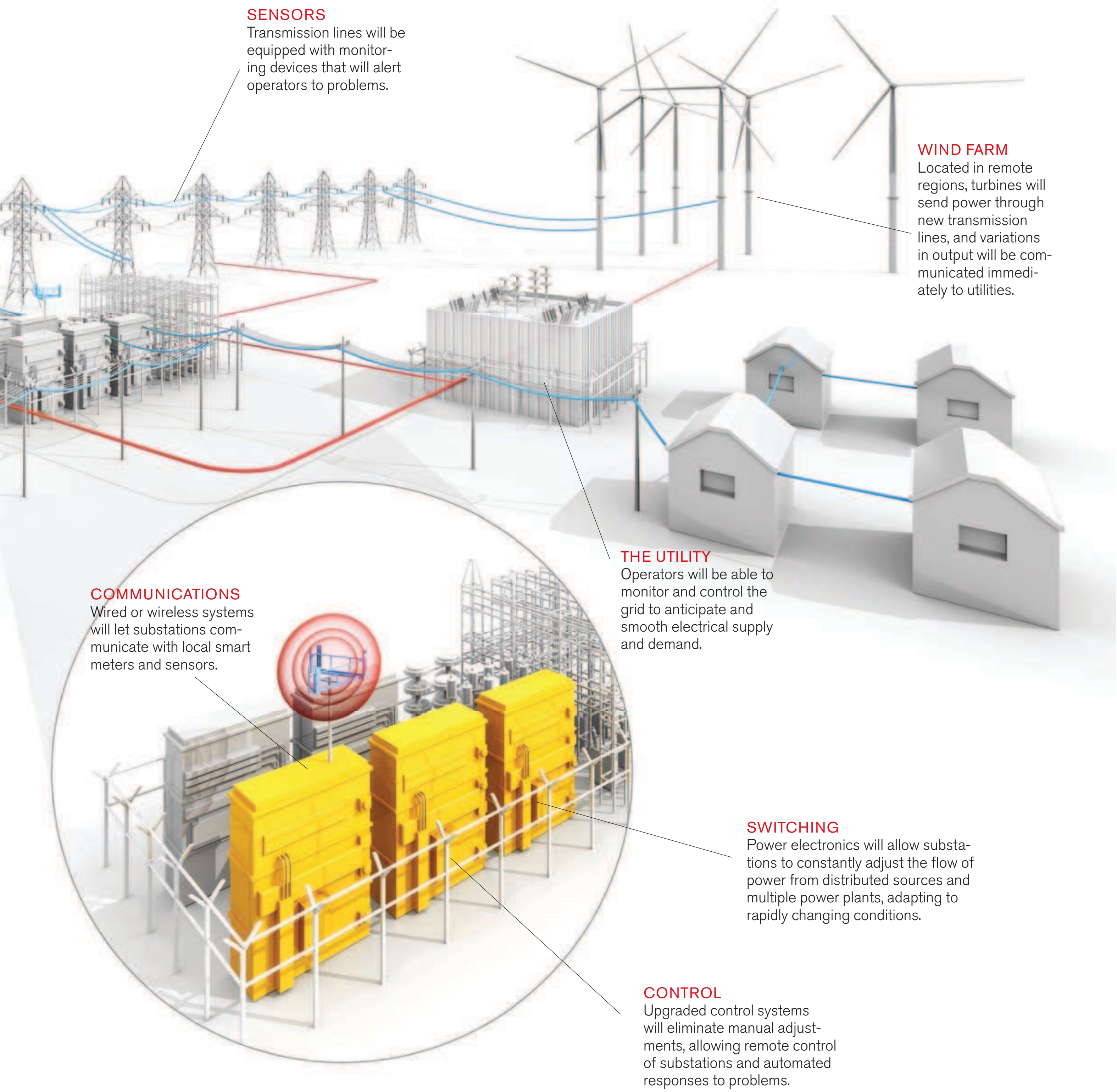
New substations that will react to commands or problems within a fraction of a second will make it possible to change from a traditional system, where electricity flows in one direction only, to one in which electricity can flow in multiple directions. Through smart meters in homes and businesses (one is shown here connected wirelessly to a substation), utilities will be able to alert customers when the spot price of electricity rises because of peaking demand. That will give them an incentive to reduce their electricity use, thereby lessening the load on the grid. Smart appliances such as air conditioners and refrigerators will be able to take these prices into account, shifting into low-power modes as needed.

Drivers of plug-in hybrids and all-electric vehicles, meanwhile, will be able to automatically adjust battery charging to use the cheapest electricity available. Ultimately, the batteries in these vehicles will act as a backup power supply: when the capacity of power plants becomes strained, car owners will be able to sell some of the electricity stored in the battery back to the utility. Similarly, homeowners will be able to sell surplus power generated by residential wind or solar-panel installations.

—Stephen Cass



BRYAN CHRISTIE DESIGN


SENSORS
Transmission lines will be equipped with monitoring devices that will alert operators to problems.
WIND FARM
Located in remote regions, turbines will send power through new transmission lines, and variations in output will be communicated immediately to utilities.
THE UTILITY
Operators will be able to monitor and control the grid to anticipate and smooth electrical supply and demand.
COMMUNICATIONS
Wired or wireless systems will let substations communicate with local smart meters and sensors.
SWITCHING
Power electronics will allow substations to constantly adjust the flow of power from distributed sources and multiple power plants, adapting to rapidly changing conditions.
CONTROL
Upgraded control systems will eliminate manual adjustments, allowing remote control of substations and automated responses to problems.

reviews

VIRTUAL REALITY

Serious Games

The online world of Second Life seemed like the next big thing, only to be largely written off. Neither hypers nor detractors understood it.

By JULIAN DIBBELL

If you had to say exactly when the wave of media hype about the online virtual world Second Life crested, you could probably point to the night America got a good look at Dwight Schrute's avatar.

The October 2007 episode of NBC's hit comedy *The Office* in which the insufferable, bad-tie-wearing lead salesman Dwight was revealed to be a longtime Second Life "resident"—complete with an elaborate virtual sales office he had built there and a bad-tie-wearing little 3-D-graphical version of himself—topped a year and a half of steadily increasing Second Life buzz. With its vast, user-crafted environment of floating mansions and flying avatars, population growth of a million new accounts a month, and bustling virtual markets fueled by a robust currency (the Linden dollar, readily convertible to U.S. dollars at about 260 to 1), Second Life had been on the covers of *BusinessWeek* and *Newsweek*. Its virtual economy had been hailed as fertile ground for small-time entrepreneurs and big-brand marketers alike, and its "more intuitive" 3-D interface had been tipped as a potential replacement for the Web browser itself. If people still didn't get it, all you could do was sigh and wearily break it down for them the way Dwight did for his office nemesis, Jim Halpert: "Second Life is not a game. It is a multi-user virtual environment. It doesn't have points or scores. It doesn't have winners or losers."

"Oh, it has losers," replied Jim, deadpan. And three years later, the score is clear: Second Life and the company behind it—San Francisco–based Linden Lab—haven't come close to meeting the expectations produced by the buzz. "By 2011, four of every five people who use the Internet will actively participate in Second Life or some similar medium," the 2007 *Newsweek* story declared, citing a study by the market research firm Gartner. But even then, many of the major brands that had flocked to Second Life as a cutting-edge marketing space (among them American Apparel, Toyota, and Coca-Cola) were running up against an awkward fact: of the millions of Second Life account holders they were there to reach, only a fraction bothered to log in much. By the end of 2008, the corporations' lavish virtual storefronts were largely abandoned, and Second Life's growth slowed. By mid-2010 the respectable profits Linden Lab had long enjoyed—by the ingenious means of keeping Second Life land in scarce supply and selling it to users at up to $15 per virtual square kilometer—seemed to be in trouble too, as Linden cut staff and shuffled CEOs. Seekers of the next big thing had moved on to the richer fields of Facebook and Twitter and Apple i-gadgets.

Second Life
www.secondlife.com

Life 2.0
PalmStar Entertainment and Andrew Lauren Productions, 2010

But what if Second Life deserves a second look? After all, it didn't die when the hype did. The traffic and revenue that remain (800,000 monthly active users who generate more than $80 million a year, by the latest estimates) suggest that it will be with us for a while—maybe even long enough for those who have written it off to realize that what Second Life does best has never been and never will be what everyone seemed to want it to do.

Behind the fascination with Second Life's economic productivity lurked an almost transcendental vision of what Second Life was ultimately about. The essence of that vision was a sci-fi concept that had inspired Linden Lab almost from the start: the "metaverse." The name came from Neal Stephenson's 1992 novel *Snow Crash*, but the idea was all over science fiction in the decades before Second Life's 2003 launch. It could be found in William Gibson's "cyberspace" novels, in the Wachowski brothers' *Matrix* movies, in the ethereal computerized realms of the 1982 Disney classic *Tron*. For many virtual-world developers, both within and outside Linden Lab, it had become a given that one day we'd all experience the networked digital universe much the way the characters in these fictions do: as, literally, a universe. "Metaverse," more precisely, referred to a parallel, immersive world of concrete data in which our bod-

NEVER MIND American Apparel closed a virtual store it had in Second Life.

ies would move with the speed of thought and where much of our productive activity would take place.

By the time Second Life was booming, its more or less official long-range plan was to become the metaverse—the dominant portal to a brave new 3-D Internet. The radical efficiencies made possible by logging in to virtual worlds rather than traveling to physical places—offices, classrooms, shopping malls—became the central selling point for Linden Lab. For the company's charismatic founder, Philip Rosedale, erasing distinctions between the real and the virtual was almost a form of enlightenment, a way of understanding life on its deepest level. "Things are real because they're there with us and we believe in them," Rosedale says in a remarkable moment early in *Life 2.0*, Jason Spingarn-Koff's 2010 documentary about Second Life. "And if they're simulated on a digital computer versus sort of simulated by atoms and molecules, it doesn't make any difference to us."

This, in its purest form, is the Second Life that blew the media's mind: not an escape from or even an imitation of reality but an expansion of it, potentially suitable for almost any human purpose. But as *Life 2.0* testifies, the Second Life that blew the media's mind turns out not to be the Second Life its inhabitants have made. This Second Life—documented in the film's three in-depth portraits of more or less typical users—is less transcendent but no less profound. And it's something that can't really be recognized without understanding Second Life to be precisely what we've so often been told it's not: a game.

To be sure, the activities we see in *Life 2.0* aren't games by any standard definition of the term. In the first portrait, a married man in Canada and a married woman in the United States meet in Second Life, have a passionate affair by way of walks in virtual forests and avatar sex, and end up leaving their marriages for an ultimately failed attempt at living together. In the second, a young man engaged to be married spends several months in Second Life obsessed with playing the role of a little-girl DJ, for reasons he struggles to understand. And in the third, we meet a woman who lives with her parents in working-class Detroit and makes a real if unreliable living selling impossibly luxurious houses and fashion in Second Life. However serious the stakes in these pursuits, there is no escaping the element of play in all of them—of fantasy and make-believe—and the ways in which the dollhouse world of Second Life is uniquely suited to it.

The warts-and-all intimacy of these profiles is discomfiting at times, and it's no surprise other Second Lifers have complained about Spingarn-Koff's choice of stories. Could he not, perhaps, have interviewed

some of the many now happily married couples who met in Second Life? Or how about some role players who aren't skirting the edge of pedophilia? Or some of the many creative artists who use Second Life as a canvas, or the even greater number of Second Life "fashionistas," whose blogging about in-world fashions and endless buying and selling of virtual styles turns out, apparently, to be the single most popular activity in Second Life?

He could have. But the common thread running through almost any configuration of Second Life stories would have been the same: Dressing up. Flirting. Philandering. Playing records. Playing house. Building castles and curiosities out of endlessly editable virtual objects ("like the building blocks you had as a kid," one *Life 2.0* protagonist tells us). Second Life as it is really lived doesn't even gesture toward the broad utility its creators aimed for. It's not the promise of the metaverse. It's just a lot of people giving rein to one form or another of a basic human impulse: playing.

To insist in the face of all this that Second Life is not a game is to miss out on the way it illuminates what's becoming of that impulse. Yes, Second Life lacks points, built-in goals, and other features we have long thought definitive of games. But ever since Dungeons and Dragons introduced us to the hitherto unheard-of concept of a game that never ends, we have been living in an era that requires us to constantly revise our definitions. The evolution of video games has been a furious and ceaseless reinvention of the form. We have games now being woven into otherwise utilitarian aspects of social life, like Foursquare, and games like FarmVille that straddle the line between work and play. The future of play has never looked more open-ended, protean, and complex—or, to put it another way, more like Second Life. tr

JULIAN DIBBELL IS A FREELANCE WRITER LIVING IN TOULOUSE, FRANCE. HIS WORK HAS APPEARED IN THE *BEST TECHNOLOGY WRITING* SERIES, AND HE IS THE AUTHOR OF *PLAY MONEY: OR, HOW I QUIT MY DAY JOB AND MADE MILLIONS TRADING VIRTUAL LOOT* (BASIC BOOKS, 2006).

SOCIAL MEDIA

Start Me Up

Online crowd-funding, supported by social technologies, provides a new business model for book publishing.

By EMILY GOULD

The first literary agent that Meaghan O'Connell and Melissa Gira Grant approached about their idea for an anthology of sex-themed stories told them it would be very difficult to sell. The bloggers didn't yet have well-known contributing writers, and neither woman had published or edited much. But rather than look for another, more sympathetic agent (or get frustrated and give up), they decided to create the book themselves, with funding raised through the micropatronage service Kickstarter.

Kickstarter
www.kickstarter.com

Coming and Crying
Edited by Meaghan O'Connell and Melissa Gira Grant
comingandcrying.com

Founded in April 2009 by Perry Chen, Yancey Strickler, and Charles Adler, the "crowd-funding" site helps launch projects that meet a threshold pledge goal, which is established by the people who are seeking cash. The service has raised over $20 million for everything from films to books to music to design startups. Kickstarter's model combines investment and charity: typically, donors get some benefit in return for their gifts, such as copies of the movies or music produced, shares in a rooftop farm, or contact with artists.

For their Kickstarter home page, Grant, who has written provocatively about sex and technology for *Slate* and Gawker Media's *Valleywag*, and O'Connell, who until recently was director of outreach for the blogging service Tumblr, created and posted a video trailer. They'd decided to title the book *Coming and Crying*, and the trailer featured voice-over excerpts from the stories playing over shots of writers typing on a laptop in a café or gazing pensively out the subway window while scribbling in a notebook. Within a few hours, they'd met their $3,000 funding goal, and within six weeks they'd exceeded it by $14,242.

Suddenly, the writers realized that in order to keep their promise to their 651 sponsors, they'd have to learn not only how to edit but how to design, print, market, sell, and distribute a printed book. (No e-book or other online edition of *Coming and Crying* was to be made available—the whole point for the blogger contributors was the exotic opportunity to see their names on a physical page.) In effect, Grant and O'Connell had become publishers.

Self-publishing is not new; online publishing is not *that* new. Even publishing by subscription has a precedent: many now-famous 19th-century books were first published in small numbers and presented to a circle of subscribers. But the *way* Grant and O'Connell published *Coming and Crying* through Kickstarter really is unprecedented. Using their social and blogging networks to spark initial interest, the authors offered people who came to their Kickstarter home page the opportunity to contribute at a variety of different levels, which in turn permitted the donors different degrees of access to the book-making process. Anyone who pledged a dollar or more got to read the authors' semiprivate blog about the book, $15 guaranteed you a copy of the book, and donations above that level earned donors even more connection and intimacy: instant-messaging chats, private readings (in public places), and custom-written stories. Using this support, the two created a book that has sold 1,000 copies to date. Unless you've worked in publishing, this number probably sounds tiny, but

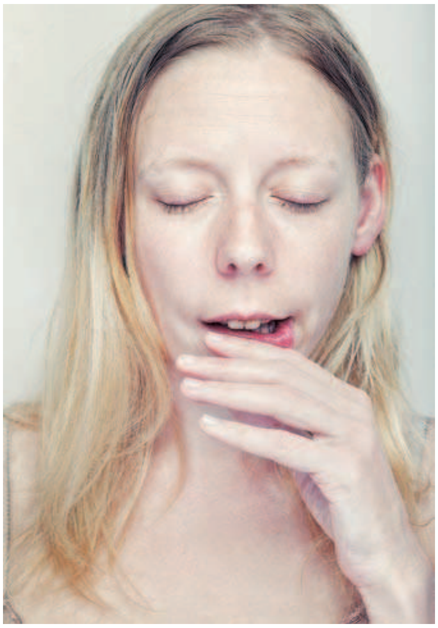
many literary novels and "quality" nonfiction works from big publishers—the kind of book you read about in the *New York Times Book Review* and the *New Yorker*—sell only three or four times this sum.

The tale of two young women who used micropatronage to create a book that a mainstream publisher in all likelihood would never have published or would have botched seems like a feel-good success story—and it is, mostly. In addition to giving a niche audience a book that it unequivocally wanted, Grant and O'Connell sidestepped the inefficiencies and inequities of the book industry—the problems that hundreds if not thousands of writers, online and off, have lately expended novels' worth of literary energy enumerating.

Complaining about the publishing industry is a genre unto itself, and the complaints are mostly valid. Publishing behemoths are great at cranking out best-sellers and terrible at uniting books that don't have mass appeal with their small (but not inconsequential) audiences. The years when publishers overstocked their lists in order to fill massive chain stores with inventory are over, but even as the chains shrivel, the overstocking continues. Many millions of dollars are wasted every year printing and shipping books that are then returned, unsold, by the bookstores and eventually pulped.

Most galling of all is the sense that now more than ever, publishers are interested only in the work of authors and "authors" who have established fans—the dreaded phenomenon known as "platform-based" publishing. (The phrase is meant to suggest a politician's platform, not a computer operating system.) Someone looking for an example of the industry's folly needn't search far: at your nearest Barnes & Noble, if it isn't one of the stores that the corporation has shuttered in the last year, you might find a copy of Shannen Doherty's new large-format, four-color inspirational life-guide/autobiography on a table near the front of the store (hot territory that publishers pay for the privilege of populating with their titles, a practice known as "co-op").

Perversely, traditional publishing is also the only organizing body that systematically discovers new literary talent—especially the kind of talent that first manifests offline. "Gatekeeping, tastemaking, editing—that's why people like books published by legitimate publishers," says the venerable literary agent Ira Silverberg. Obviously, most agents—whose business is gatekeeping—tend to dislike trends that threaten to make their jobs obsolete. But Silverberg, whose list features both mainstream heavy hitters and quirky indie darlings, doesn't oppose self-publishing, through Kickstarter or other means, for literature that is "community-based and important only to a limited number of readers": translations, poetry, culturally high-minded work. He finds that to be "a wonderful use of technology." He's just suspicious of what he calls "vanity publishing cheaply wrapped in something that pretends to be legitimate." And as more people discover that it's possible to turn online audiences into book readers without a publisher, Silverberg doesn't think this trend will enrich our cultural conversation. "Mostly we'll hear from the 'Look what I can do!' types—they tend to be the ones who the mainstream has no use for anyway," he says. "I hope they enjoy their moment. It will probably be the only one they have."



DON'T CRY FOR ME Melissa Gira Grant used the micropatronage website Kickstarter to publish a book with a small but ardent audience.

NIKOLA TAMINDZIC

The other troubling aspect of self-publishing through patronage is the precedent it establishes for authors to become beholden to donors. The idea of paying for the privilege of instant-messaging with O'Connell and Grant squicks me out, as does the recent post I read online about how a young writer named Emma Straub was selling shares in the publication of her first novella: for $10 you could buy a signed and numbered copy with a letterpress cover, and if you wrote to her and told her you'd bought a share, she responded, "I will send you a thank you note. It may even come with chocolate chip cookies. I'm serious." ("What's next, authors will send you a lock of their hair?" a friend joked.)

Literary fame, even in the microscopic or hard-to-quantify doses available on the Internet, is a powerful intoxicant. Sometimes I wonder whether young writers, especially young women, realize what they're getting into when they establish a relationship with online donors. Having patrons can be at odds with unfettered self-expression. It might also create inappropriate expectations on the part of those patrons—although this has not been the experience of O'Connell, who feels that Kickstarter actually helped her avoid sending the wrong message to people whose gifts she accepted. "One person said to me that he wanted to support me as a writer, but it would be awkward for him to write me a $100 check, and the Kickstarter thing made it less awkward—because there was a social convention for it, basically," she told me recently when we met for coffee to discuss *Coming and Crying.*

O'Connell relished the process of creating the book with Grant from scratch, even though some aspects were unexpectedly difficult. The designer they hired had never made a book before, so they pulled

books from their shelves to figure out what they liked. Writers whose work didn't make it into the anthology felt snubbed by the women's Kickstarter blog, which described sorting through and rejecting submissions. O'Connell's foray into the permanency of print after years of writing exclusively for the Web made her queasy: "If I wrote a blog post I could always go back and edit it ... but [for the book] I felt like I had to be better than I am on my blog. The hardest part was seeing it in the book and knowing I couldn't change anything."

As a business, publishing hasn't been a super-lucrative hobby for O'Connell and Grant. Still, they haven't done so badly, and unlike many publishers, they haven't actually *lost* money. Through Kickstarter, they broke even, making enough money to pay their designer, printer, copy editor, and cover photographer. After funders received copies from the initial print run, they consigned 100 copies to a local independent bookstore, at a cover price of $24, which constituted pure profit, and the remaining books were reserved for online buyers. After the 24 contributors' royalties are paid, O'Connell says, she and Grant will each make $2 a book, with $8 earmarked for "the future endeavors of the company."

At one point they thought those endeavors might include devoting themselves full-time to the small press they founded, but that ambition has now receded, partly because O'Connell has realized how hard she worked for relatively little money. "If we had to make a living on this, it would be less fun," she says. "It would kind of take the magic out of it." Her ambition is to someday publish a book on her own, and to do that she wouldn't consider using Kickstarter. "For an anthology, coedited, it made sense to publish collaboratively," she says. "If I was writing my own book, there's no way in hell I'd want to go through this. I wouldn't have the objectivity, the perspective. I would need an editor." **tr**

LONGTIME BLOGGER EMILY GOULD IS THE AUTHOR OF *AND THE HEART SAYS WHATEVER* (FREE PRESS). SHE REVIEWED MATCH.COM IN THE JANUARY/FEBRUARY 2010 ISSUE.

TELEPRESENCE

The New, More Awkward You

Robots that stand in for remote workers could force people to learn how to tolerate a new breed of social failings.

By TOM SIMONITE

When you become a robot, everyone smiles at you. That's what happened when I appeared in *Technology Review*'s office in Cambridge, Massachusetts, in the form of a four-foot-high wheeled robot with a small screen, speakers, camera, and microphones on top. The screen and speakers let my distant coworkers see and hear me at my desk in San Francisco, and the camera and microphones sent their images and voices back to me. While I sat at my computer, I could roll the robot into meetings or seek people out in their cubicles 3,000 miles away. But the smiles directed at the other me were rarely the kind I would want to receive in person. They were more like those directed at a cute but annoying toddler.

Vgo telepresence robot

Anybots telepresence robot

My robot body, a loan from Vgo Communications, could do some of the basic things I would do in person: move around the office to talk and listen, see and be seen. But it couldn't do enough. In a group conversation, I would clumsily spin around attempting to take in the voices and body language outside my narrow range of vision. When I walked alongside people, I sometimes blundered into furniture, or neglected to turn when they did. Coworkers were tolerant at first, but they got frustrated with my mistakes—much as they would if I struggled to keep up or smacked into a chair during a professional conversation in person. And my embarrassment after such errors burned no less than if I had been there in the flesh.

BEING THERE A Vgo telepresence robot roams the halls at *Technology Review.*

Vgo's and other telepresence robots just appearing on the market are embarking on the first real-world test of what happens when humans attempt to use machines as their physical stand-ins. An office near you may well be part of this experiment, because, imperfect though these body doubles are, they address a need unmet by other communication tools. Increasingly we work at a distance from our colleagues, heavily reliant on phone calls, instant messages, videoconferencing, and e-mail. But face-to-face contact in the same office is still considered the gold standard for collaboration. That's not just a gut feeling. It's backed by research showing that trust is harder to build, and more brittle, when we use telecommunication technology than when we interact in person. Telepresence robots are the first technology that attempts to replicate in-person contact and the benefits of being physically near people.

Rather than humanoids, these are wheeled robotic stick figures—and yet they can be more human than any other technology in use today. The physical footprint they occupy is similar to a person's, and users guiding the machines can try to act as they themselves would if they were there. That encourages people interacting with the robot to behave as if it were a person. Users on both sides report better recall of situations and meetings relative to videoconferencing or phone calls.

Some of the earliest adopters are bosses who want to see and be seen by their underlings at any given time. "One of our clients is CEO of a 40-person tech company in Silicon Valley that has half its engineers in Russia," says Trevor Blackwell, founder of Vgo's competitor Anybots, which began selling its telepresence robot in late 2010. Similarly, one of Vgo's first users is Neal Creighton, CEO of the Web startup RatePoint. Creighton and his sales manager are often on the road and need to keep their sales force of 25 people motivated. "It's possible to roll around, be seen to be listening to the calls going on, and provide coaching based on what we

HI, ROBOT The Vgo machine lets the San Francisco–based reporter converse with a colleague as he walks down a corridor at *Technology Review*'s Cambridge office.

hear," says Creighton. "I'd estimate we see a 15 to 20 percent lift in results compared to not having the robot." Another Vgo owner uses the robot to inspect goods rolling off production lines in China.

For a business tool, these robots are relatively cheap, especially when compared with the cost of travel or high-end videoconferencing systems, which can run into the tens of thousands of dollars. Anybots charges $15,000 for a bot. Vgo charges $5,000 up front plus a yearly support fee of $1,200—less than a business-class ticket from San Francisco to Beijing.

Unfortunately, having robots stand in for people "makes them subject to dangerously high expectations," says Clifford Nass, a Stanford University professor of communications and computer science whose recent book *The Man Who Lied to His Laptop* explores how we relate to technology. "If they were built like TV sets on wheels it would be totally different."

Almost all studies of how humans interact with robots have looked at autonomous, intelligent robots capable of helping people in their homes. But the lessons of that research are equally applicable to telepresence robots, Nass argues, because they are meant to simulate a human's roles and behaviors. One such lesson is that humans expect robots to act like humans—to follow human rules about social space and body language. When the robots fail at that, people feel insulted and annoyed. Other experiments have shown that robots—and people—that move jerkily or react slowly are routinely judged to be of inferior intelligence. Such failings in a telepresence robot may reflect on the person controlling the machine, not the offending electronics, and could harm the very professional relationships these machines are supposed to help. "We give other people credit and blame for the body they have, and in this case your body is the robot," says Nass. "It's meant to be you, and so it better act like you."

Practice at using a telepresence robot does cut down on the blunders. But despite their pilots' best efforts, they will inevitably move and act strangely at times because of their less-than-human senses and range of motion. Their operators will also have to shoulder the burden of technical glitches. I found the fallout of a poor connection caused by a flaky wireless router, for example, to be nothing like that of a dropped phone or video call. In one meeting, as the audio connection faltered and my voice broke into digital static, I could see the annoyance spread on my colleagues' faces. When the connection dropped entirely, I was embarrassed that my body had become their problem, stranded in the middle of the room. When I logged back in, I was being borne across the office in someone's arms like a child.

A logical response from the builders of these robots is to keep fine-tuning them. Willow Garage, a company in Menlo Park, California, that is developing its own telepresence robot, found in field studies with local companies that bad driving of the machines has more serious consequences than scratched paintwork. "The pilot tends to feel very embarrassed and laugh," says Leila Takayama, a researcher at Willow Garage. "That makes people feel that the pilot is goofing around and not taking them seriously." The company is experimenting with algorithms that take over and steer a person around obstacles, a strategy that Anybots also uses. It's possible to imagine other technical features that could act as social prosthetics; for example, a robot could be programmed to automatically respect personal space.

Upgrading telepresence robots to make them slicker at navigating the office may actually make the problem worse, though. Nass cites the "uncanny valley" hypothesis, which holds that technologies too closely imitating human form and behavior can elicit more negative emotional responses than less realistic ones. In other words, adding features that improve the ability of these robots to act human may actually make them less easy to tolerate. To get their machines out of the uncanny valley, engineers will need to make them either incredibly human-seeming or less so than they are now. The former won't happen any time soon, and the latter seems undesirable for telepresence robots whose reason for being is to fill in for people.

If these robots are to introduce an era of effortless interaction with machines, the changes may have to come from us, not them. "As these machines appear in the workplace, we will see completely new social norms forming around them," says Takayama. We humans may have to learn to judge people represented by electronic bodies differently from those we can see in the flesh. tr

TOM SIMONITE IS *TECHNOLOGY REVIEW*'S IT EDITOR FOR SOFTWARE AND HARDWARE.

hack

Microsoft Kinect

How the device can respond to your voice and gestures

By ERICA NAONE

THE MICROSOFT KINECT is the first consumer product that lets people control an interface using gesture and voice alone. An add-on for Microsoft's Xbox 360 video-game console, the sensor-packed device can determine your position and interpret vocal commands, all without requiring you to hold any special controllers or wear special clothing. At $150 retail, it is a relatively inexpensive way to try a next-generation interface. You might, for example, play Dance Central, a movement game made by Harmonix that teaches dance moves, watches how well you perform them, and tracks how many calories you burn during a play session.

A INFRARED

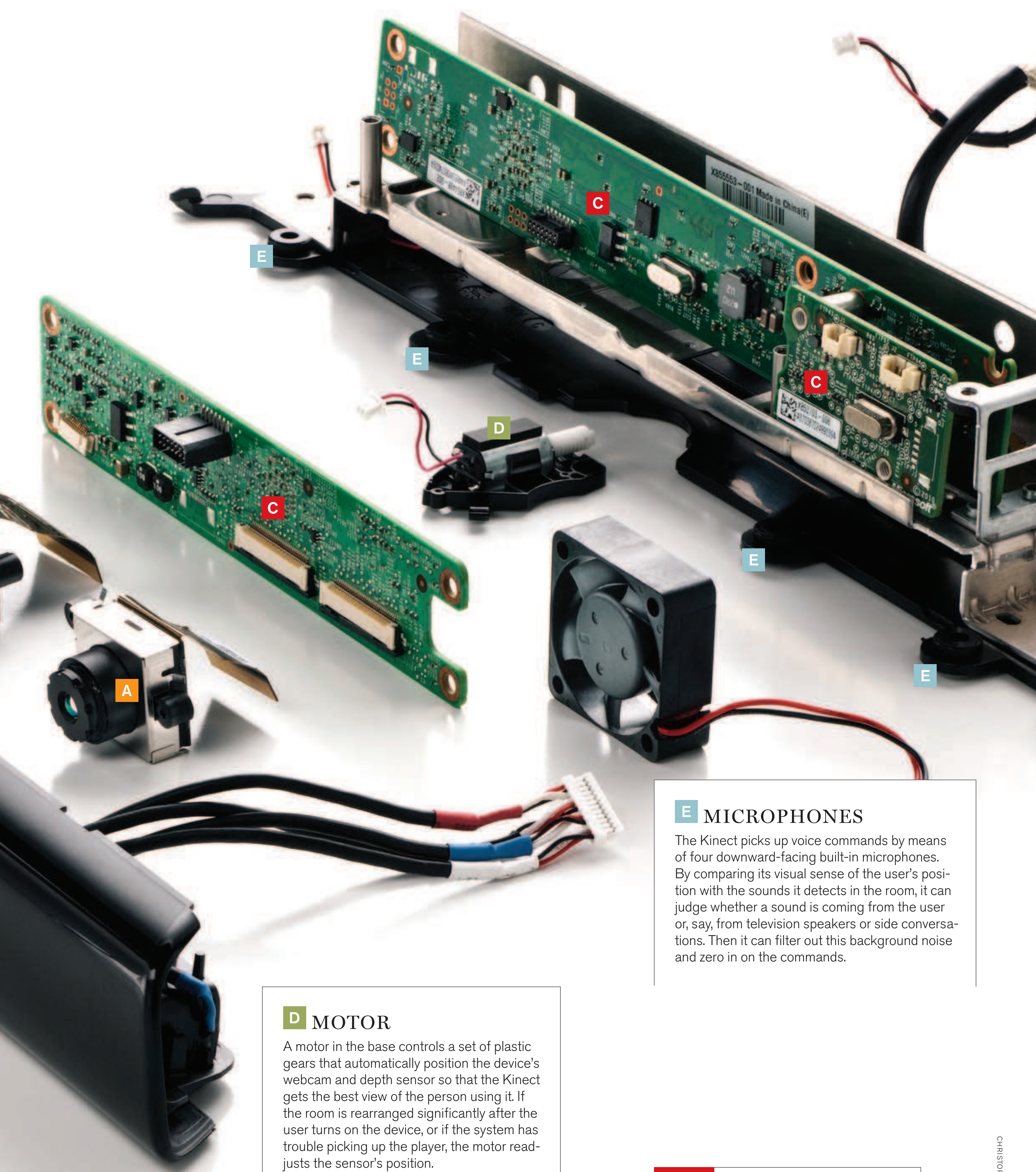
An infrared projector and camera give the Kinect its depth perception. By measuring how long the emitted infrared light takes to reflect back from objects it encounters, the device can figure out the room's layout.

B CAMERA

Another camera picks up the normal human visual spectrum. In addition to helping the device determine a user's position, it takes photos of people playing games. Users can share these photos through Xbox Live.

C LOGIC

The brains of the Kinect are split across three circuit boards. One board contains chips that process audio input, another has an accelerometer that monitors the device's tilt, and the third has a chip that handles the image processing.



E MICROPHONES

The Kinect picks up voice commands by means of four downward-facing built-in microphones. By comparing its visual sense of the user's position with the sounds it detects in the room, it can judge whether a sound is coming from the user or, say, from television speakers or side conversations. Then it can filter out this background noise and zero in on the commands.

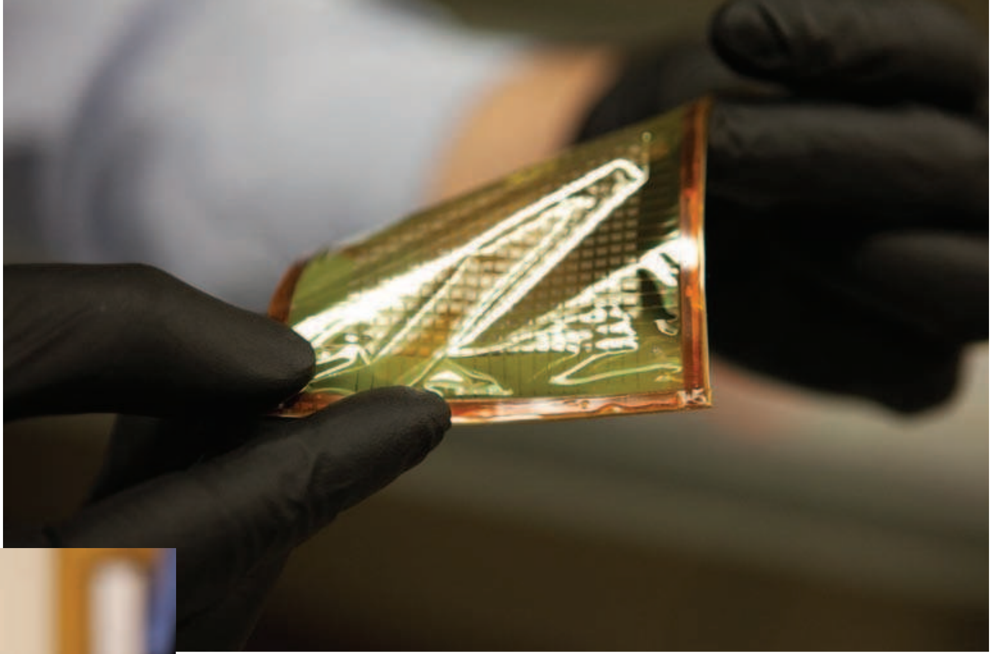
D MOTOR

A motor in the base controls a set of plastic gears that automatically position the device's webcam and depth sensor so that the Kinect gets the best view of the person using it. If the room is rearranged significantly after the user turns on the device, or if the system has trouble picking up the player, the motor readjusts the sensor's position.

WWW See the Kinect in depth: **technologyreview.com/hack**

CHRISTOPHER HARTING

demo



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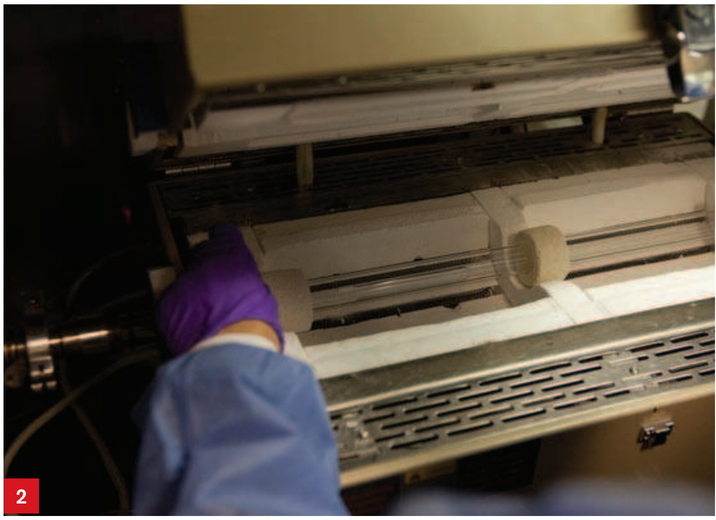


2

Printing Electronic Skin

University of California researchers are making sheets of speedy, low-power transistor arrays for sensors that match human skin's sensitivity.

By KATHERINE BOURZAC

Ali Javey rolls a glass cylinder coated with nanowires over a thin plastic film. With a single motion, he lays down a dense array made up of millions of silicon-germanium nanowires arranged in parallel. Flexible sheets like this one will form the basis for the largest arrays of high-performance nanowire transistors ever made: seven by seven centimeters.

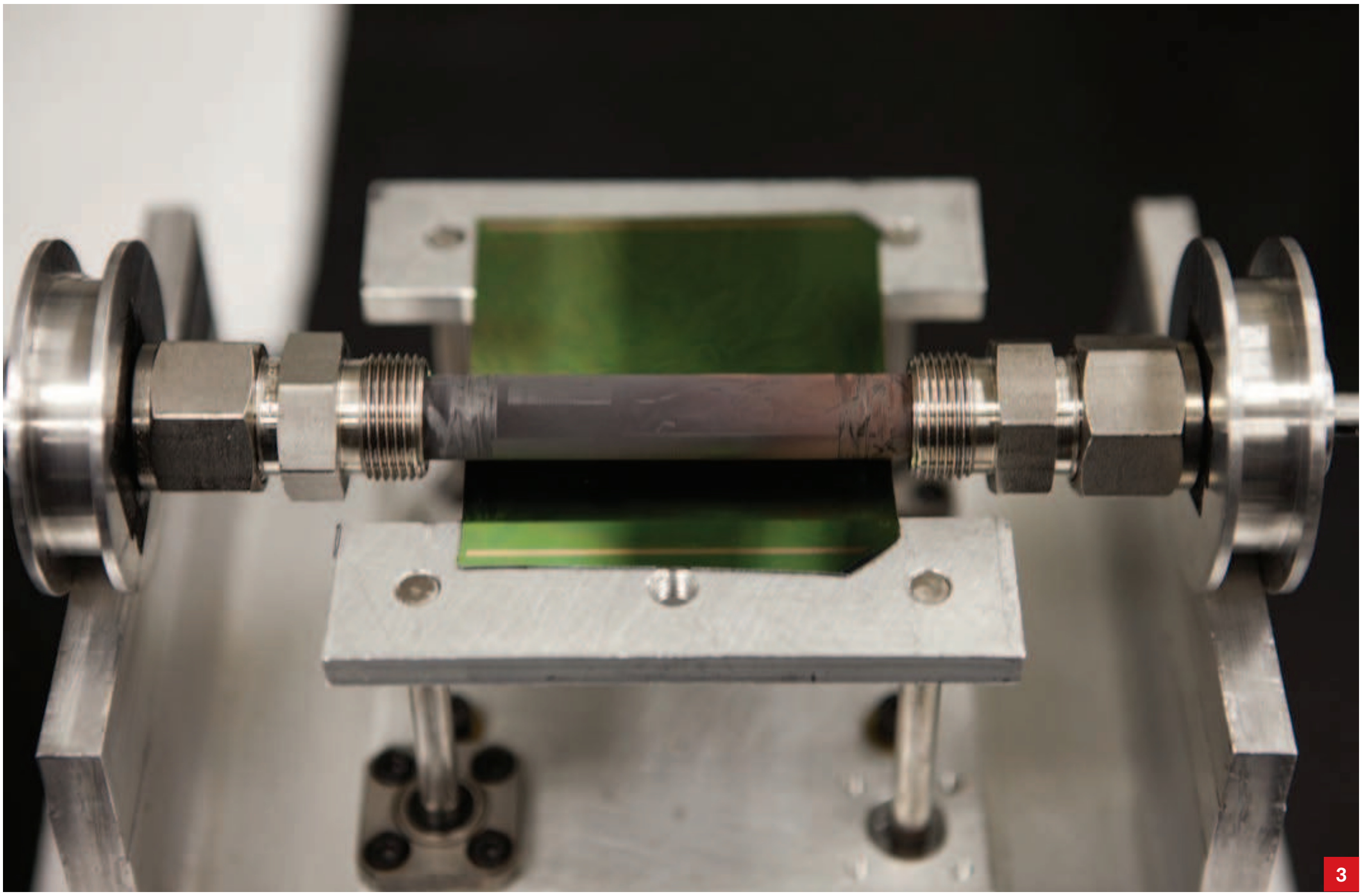
Javey, a professor of electrical engineering and computer science at the University of California, Berkeley, has turned the sheets into pressure sensors that are as sensitive as human skin, which can detect even the tiny force exerted by a fly when it lands on your arm. His "electronic skin" can be made to cover large areas, and it requires very little power. Sheets of the skin could bring a sense of touch to prosthetics, and they could be incorporated into probes used in minimally invasive surgical procedures, providing tactile feedback that would help doctors navigate better.

Javey also plans to use the basic fabrication method to achieve a larger goal: using nanowires to make speedy, flexible low-power electronics for displays. Conventional chips are made of brittle materials, so they can't be used for applications that require flexibility; flexible organic materials, on the other hand, typically don't perform well. Many chemists looking for a way to produce high-performance flexible devices have proposed making them from conventional chip materials in the form of nanowires, because nanowires don't break when arrayed on flexible surfaces. But it's been difficult to put together arrays of nanowires that perform up to their potential in electronics. Javey's technique at last provides a way to do this.

PAINTING WITH NANOWIRES

The first step in the process is loading up the roller with nanowires. Javey uses established techniques to grow the nanowires on the surface of the roller, which is simply a glass test tube. Graduate student Toshitake Takahashi coats the outside of the tube with a red liquid containing gold nanoparticles in suspension. Each particle will act as a

JEN SISKA



seed to catalyze the growth of an individual nanowire, whose diameter depends on the particle's size. Takahashi fits the tube inside a chemical-vapor deposition apparatus. He then closes the chamber, raises the temperature inside to several hundred degrees Celsius, and flows in silane and germane gases, which will provide the ingredients for the silicon-germanium nanowires. The wires sprout up at a rate of about one to five micrometers per minute, reaching their full length in 10 minutes or less.

When the tube is taken out of the machine, nanowires coat its surface like nanoscopic brush bristles, making it appear matte black. Now it's ready to be used in the printing process, which Javey says originated by accident. "I noticed that rubbing an array of nanowires onto a surface, even by hand, transferred aligned nanowires, as long as you rubbed directionally," he says. He started transferring the nanowires with a cylindrical roller so that he could print larger arrays at one time.

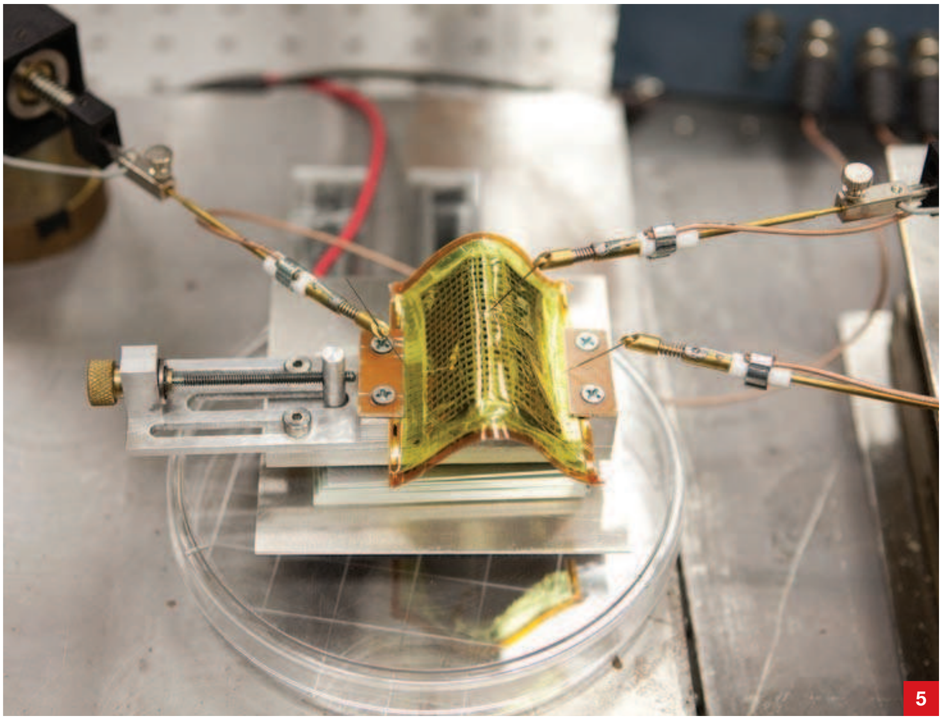
Javey built the printer, a tiny steel table that supports the printing surface and the roller, in the Berkeley machine shop. The nanowire-coated glass tube fits between two wheels that move along tracks on either side of the device, helping to keep the rolling motion uniform and prevent any wobbling that might misalign the nanowires.

He pushes the roller across a square of polyimide plastic; when the nanowires touch its surface, their tips stick to it. As the roller moves forward, these clinging nanowires are pulled in the same direction and finally detach from the cylinder, all oriented the same way. The process continues until all the nanowires have been transferred to the plastic. To make transistors, Javey uses conventional processes to deposit nickel electrodes and aluminum gates on top of the nanowire arrays.

The uniform orientation of the wires is critical to the performance of nanowire electronics. Researchers have made high-quality transistors from single nanowires,

University of California professor Ali Javey has developed a new way to make nanowire-based electronics. His first application is electronic skin (top left). Each small square on this plastic sheet is a nanowire-based transistor that can sense pressures as slight as a fly alighting on a surface.
1. The process begins with a suspension of gold nanoparticles (red liquid in jar). Each particle will catalyze the growth of a single nanowire.
2. After a glass tube is coated with the nanoparticles, it's placed inside a chemical-vapor deposition apparatus, where it will be exposed to silane and germane gases.
3. The tube, black with nanowires after emerging from the machine, is mounted onto a roller printer, which deposits straight rows of nanowires to form well-ordered arrays.

but this requires painstaking techniques that can't be used for manufacturing. Others have used simpler techniques to make transistors from groups of tangled nanowires without trying to align them. But if the nanowires are in disarray like a pile of pick-up sticks, electrons moving through them take much longer paths and leak out where the wires cross, reducing the current that flows through the transistor and wasting electricity. If the nanowires are all lined



up, electrons take a straight path through them and move easily from the tip of one into the next. Javey's transistors match the performance of single-nanowire transistors but are much easier to produce. "We're essentially painting wires down," he says.

4. Working in a clean room, where the light is yellow to protect photosensitive materials, researcher Kuniharu Takei uses conventional photolithography to add electrical connections to the nanowires, forming transistors. Inside this machine, he exposes the nanowire array to a lithographic mask to create a template that will guide the placement of metal sources, drains, and gates.
5. The completed electronic skin, shown here, has been laminated with a transparent pressure-sensitive material. The final step is to test the skin's performance when flexed. The metal arm on the left of this device bends the sheet while probes monitor its electrical output.

THIN-SKINNED

To turn the nanowire array into a pressure sensor, Javey tops it with a sheet of specially treated rubber whose electrical resistance changes when pressure is applied. That causes an abrupt change in the current flowing through the nanowire transistor under that spot; this change can be detected and used to measure the pressure there. The seven-centimeter-square array contains a total of 342 such pressure-sensitive points. The material is so resilient that it can be bent thousands of times without degrading its performance.

In addition to being extremely sensitive, the device requires relatively little power. Pressure sensors have been made with transistors before, but those devices are based on lower-performance organic materials that impose much higher voltage requirements—10 volts, whereas the Berkeley devices can be powered by just two to three volts. Decreasing the voltage, and thus the power consumption, is particularly important for applications such as prosthetics.

Low-power flexible transistor arrays would also be promising for use in displays, says Javey; they could take the place of the heavy, fragile glass-backed arrays of silicon transistors that control the pixels in today's displays. Future devices could use stacked nanowire arrays, one layer acting as a pressure sensor for a touch screen while another provided electronic controls for display pixels.

Javey's printing method works with any type of inorganic nanowires, and he's used it to print active materials for solar cells and light sensors. The ability to generate power, sense light and pressure, and display information might be integrated into lightweight, flexible low-power devices that have yet to be designed. But first, Javey must scale up the technology.

WWW Watch a demonstration of electronic skin being printed: **technologyreview.com/demo**

"Right now we're limited by the size of our tools," he says. Another problem is that the quality of the nanowire arrays can be inconsistent because the actual printing is done outside a clean room, using "home-built" equipment. "We want to make the process better controlled and get more uniformity with the printing," says Javey. "If we can improve the process, we'll transfer it to industry." Then the technology can be incorporated into commercial products.

"For nanowire devices, this printing approach is the best in town," says John Rogers, a professor of materials science and engineering at the University of Illinois at Urbana-Champaign. "It offers unprecedented capability at building nanowires into sophisticated devices over areas and at yields that look interesting from a practical perspective." tr

from the labs

BIOMEDICINE

Stem Cells Made with RNA

A new technique could provide safer cells for human therapies

SOURCE: "HIGHLY EFFICIENT REPROGRAMMING TO PLURIPOTENCY AND DIRECTED DIFFERENTIATION OF HUMAN CELLS WITH SYNTHETIC MODIFIED MRNA"
Derrick J. Rossi et al.
Cell Stem Cell 7(5): 618–630

RESULTS: Researchers used four types of RNA molecules to "reprogram" adult cells so that they behaved like embryonic stem cells, which are capable of turning into any cell type. Then they used them to create muscle cells. The new method is 100 times as efficient as conventional cell reprogramming methods, which use DNA rather than RNA.

WHY IT MATTERS: Scientists would like to be able to create personalized replacement tissue by turning a patient's own cells into stem cells and then coaxing those cells to differentiate into the type of tissue that has been lost or damaged by disease. The most common reprogramming technique involves inserting four genes into an adult cell. But this type of genetic engineering might increase cancer risk, so the resulting cells cannot be used in human therapies. The new method is one of several DNA-free approaches now under development.

METHODS: The researchers created synthetic RNA molecules, adding chemical modifications that enabled the molecules to escape immune attack when introduced into a cell.

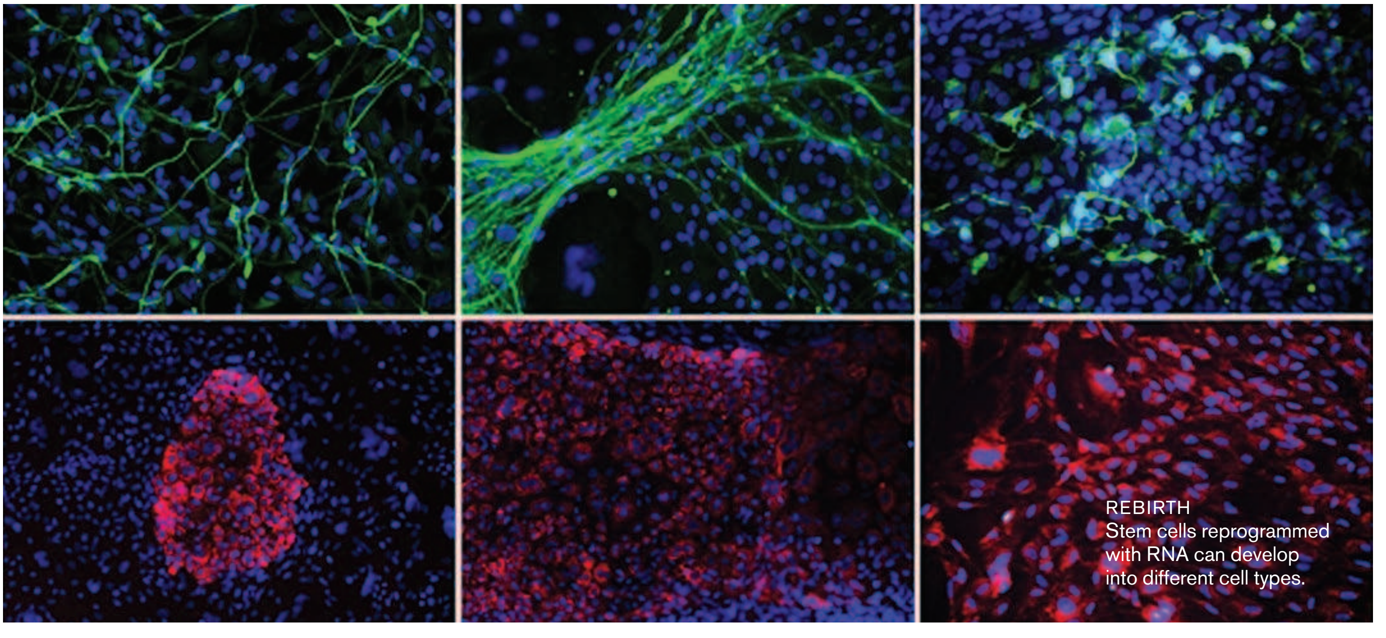
NEXT STEPS: Additional molecular testing must confirm that the cells created from these reprogrammed cells closely resemble normal adult versions. Derrick Rossi, the Harvard researcher who developed the technology, has started a company to commercialize it.

Stroke Therapy

A drug that blocks inhibitory nerve signals improves recovery

SOURCE: "REDUCING EXCESSIVE GABA-MEDIATED TONIC INHIBITION PROMOTES FUNCTIONAL RECOVERY AFTER STROKE"
S. Thomas Carmichael et al.
Nature 468(7321): 305–309

RESULTS: Researchers found that after a stroke, neurons near the damaged part of the brain are blocked from firing, which makes it more difficult for the brain to incorporate them into new circuits that might compensate for the damage. The problem stems from the buildup of a molecule that inhibits the neurons' signaling functions. By treating stroke-damaged mice with an existing compound three days after inducing the



REBIRTH
Stem cells reprogrammed with RNA can develop into different cell types.

PHIL MANOS/CELL PRESS

stroke, the researchers were able to block the effects of this buildup. The treatment boosted recovery of motor function by 30 to 50 percent.

WHY IT MATTERS: The brain has some ability to "rewire" itself after a stroke, in which a blood clot blocks blood flow to a part of the brain and deprives it of oxygen. Even with intensive rehabilitative therapy, however, most patients never fully recover lost movement or language skills. Existing drugs for stroke prevent the blood clot from doing additional damage, but they do not enhance the brain's ability to rewire. In addition, the drugs must be taken within a few hours of the stroke, and not all victims can get help in time.

METHODS: After inducing a stroke in mice, researchers found that a transporter molecule normally responsible for removing the inhibitory chemical from brain tissue was no longer functioning properly. But giving the mice an experimental drug known to suppress the action of this chemical improved their motor function.

NEXT STEPS: The researchers now plan to test whether the same treatment works for different types of strokes in different parts of the brain. The experimental drug used in the study is not approved for human use, so the team wants to work with pharmaceutical companies to encourage clinical testing of this compound or others that have a similar effect.

INFORMATION TECHNOLOGY

Tracking Social Spam

Hacked Facebook accounts produce most of the spam on the world's largest social network

SOURCE: "DETECTING AND CHARACTERIZING SOCIAL SPAM CAMPAIGNS"
Hongyu Gao et al.
ACM Internet Measurement Conference, November 1–3, 2010, Melbourne, Australia

RESULTS: In the first large-scale study of spam activity on Facebook, researchers at Northwestern University and the University of California, Santa Barbara, showed that most of these messages originate from compromised accounts rather than from phony profiles. Spammers use those accounts to send messages to a victim's friends. Typically, the messages contain links to pharmacy sites or pages that attempt to steal more account details.

WHY IT MATTERS: With more than half a billion users, Facebook is a tempting target for spammers but one that is much more difficult to exploit than e-mail. Understanding how spammers are using Facebook is important to developing defenses against them as the network continues to grow and as attack strategies evolve. Academics say that publicly reporting spam also encourages Facebook to be more forthcoming about its efforts to protect users from this activity.

METHODS: Facebook is built around the concept of letting you share information only with other users you have chosen to connect with. But until late 2009, most users were part of regional "networks" that allowed all the people in, say, a given city or university to access one another's profiles. The researchers made use of that feature and joined several large regional networks. They then downloaded the profiles and public messages of roughly 3.5 million users. The public messages obtained were analyzed for traces of spam activity.

NEXT STEPS: The researchers plan to share their results with Facebook to help the company reduce spam and identify telltale patterns that could be used to spot accounts taken over by spammers. They will also continue to run similar analyses to track how spam activity and strategies change.

Fast Processing

A new algorithm could speed image processing, recommendation systems, and more

SOURCE: "APPROACHING OPTIMALITY FOR SOLVING SDD LINEAR SYSTEMS"
Ioannis Koutis et al.
IEEE Symposium on Foundations of Computer Science, October 23–26, 2010, Las Vegas, Nevada

RESULTS: A new algorithm offers a significantly faster way to solve certain systems of linear equations. The Carnegie Mellon researchers who created the algorithm say it could enable an ordinary desktop computer to solve billion-variable systems in seconds.

WHY IT MATTERS: The equations that this algorithm can solve have a wide variety of practical applications. For example, Netflix uses them to factor in myriad variables in making movie recommendations. In image processing, they are used to identify different parts of a picture and remove blurry spots. They are also used to optimize systems—calculating, for example, the maximum number of vehicles that can run through a network of highways.

METHODS: To solve a complex set of equations, researchers typically start by producing a simplified version that is easily solved. This version can guide them in tuning the steps to solving the full system of equations. In the new study, the researchers

used a combination of graph theory techniques to come up with a much better way to simplify the system.

NEXT STEPS: The algorithm can be used to create new "solvers"—series of algorithms that can solve for the variables in a given system of linear equations. The researchers are working to extend their methods to different types of linear-equation systems, which would allow them to solve more types of real-world problems more efficiently.

MATERIALS

More Power per Photon

Researchers demonstrate a way to convert more of the energy in light into electricity

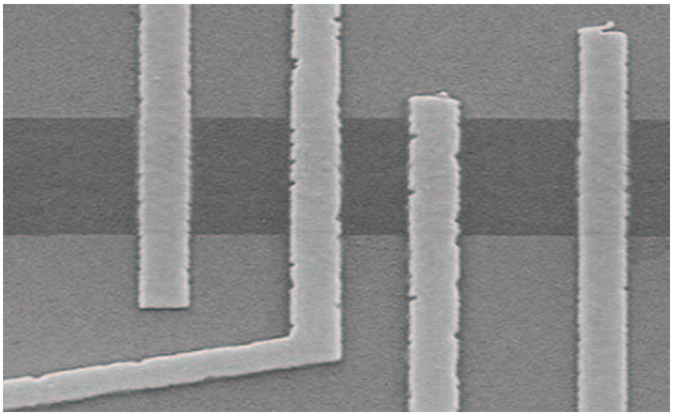
SOURCE: "MULTIPLE EXCITON COLLECTION IN A SENSITIZED PHOTOVOLTAIC SYSTEM"
Bruce Parkinson et al.
Science 330: 63–66

RESULTS: Researchers created a solar cell capable of collecting multiple electrons for each high-energy photon absorbed, and they managed to directly measure the electron output.

WHY IT MATTERS: Although researchers have steadily increased the amount of electricity that solar cells can produce, they face fundamental limits imposed by the physics of converting photons to electrons in semiconductor materials. Conventional solar cells convert only one wavelength of light efficiently; either they fail to absorb other wavelengths of light or they throw away extra energy as heat. The researchers have shown that it's possible to capture some of this extra energy, by transferring the energy in each high-energy photon to more than one electron. The approach could be used to produce ultraefficient yet inexpensive solar cells.

METHODS: Although other researchers had confirmed that a photon's energy can be transferred to more than one electron, no one had directly measured this phenomenon in a solar cell because the extra electrons are too short-lived. In this case, however, the researchers used semiconducting nanocrystals called quantum dots as the active solar-cell material, modifying their surface chemistry to create a strong bond between them and a semiconducting oxide crystal substrate. The bond allowed the electrons to move quickly from the quantum dots into the semiconductor, where they were measured as current.

NEXT STEPS: The active material in the quantum-dot test cells is so thin that almost all light passes through it unabsorbed. The researchers suggest solving this problem by adding a thin layer of it to an extremely porous material with a large surface area. The researchers are also working with different types of quantum dots that have the potential to absorb and convert more light.



TRIPLE TIME This single-transistor amplifier, a strip of graphene crossed by metal electrodes, does with one transistor what now requires many.

ALEXANDER A. BALANDIN AND GUANXIONG LIU

Three-Way Transistors

A single graphene transistor can do the work of multiple conventional ones

SOURCE: "TRIPLE-MODE SINGLE-TRANSISTOR GRAPHENE AMPLIFIER AND ITS APPLICATIONS"
Kartik Mohanram et al.
ACS Nano 4: 5532–5538

RESULTS: Researchers built a single-stage graphene transistor amplifier and demonstrated that it can perform three functions in one: it can conduct positive charge, negative charge, or both simultaneously. The device can encode a data stream by changing the frequency or the phase of a signal—a task that usually requires multiple transistors in a circuit.

WHY IT MATTERS: Previous research on graphene has focused largely on how fast it conducts electrical charge; graphene transistors are 10 or more times as fast as silicon ones. The new work demonstrates that they have other advantages as well. Because a single graphene transistor can do the work of multiple silicon transistors, graphene could be integrated into more compact chips for wireless telecommunication devices, such as RFID tags and Bluetooth headsets.

METHODS: Researchers at Rice University hypothesized that a graphene transistor with three electrical terminals, the structures that control and conduct current flow, could be operated in such a way that the transistor would switch between states where it conducts positive charge, negative charge, and both. Using standard techniques for making graphene circuits, researchers at the University of California, Riverside, fabricated the circuits, adding metal electrodes and an off-chip resistor to a small piece of single-layer graphene. Tests demonstrated that the resulting single-stage amplifier behaved as predicted, switching states when different voltages were applied. The device could also act as an amplifier in common methods of transmitting data through digital modulation of a reference signal.

NEXT STEPS: The researchers are now attempting to integrate multiple graphene transistors into a circuit for more complex applications. tr

Alumni-to-Alumni Directory & Classifieds

Upcoming Events

South by Southwest (SXSW)
Interactive Festival
March 11-15, 2011
Austin, TX
http://sxsw.com

TR35 Italy
March 17, 2011
Padova, Italy
www.technologyreview.it

EmTech India
March 22-23, 2011
Bengaluru, India
www.emtechindia.in

MIT Sloan CIO Symposium
May 18, 2011
Cambridge, MA
www.mitcio.com

TR35 Spain
June 2011
Madrid, Spain
www.technologyreview.com/es

EmTech China
Summer 2011
www.emtechchina.com

EmTech@MIT 2011
September 2011
Cambridge, MA
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STATE OF THE ART The FCC hoped that this 1939 GE television would be useful "indefinitely."

SCHENECTADY MUSEUM; HALL OF ELECTRICAL HISTORY FOUNDATION/CORBIS

Chaos in TV Land

If you think the future of television is uncertain now, look at the issues the medium faced before it took off.

By MATT MAHONEY

As more and more Internet-connected televisions hit the market, they can be expected to bring the chaos of the Web to the relatively well-ordered world of TV. For decades, until recently, the question of what any television could be expected to do was settled. A TV displays content—more or less of it depending on the viewer's cable subscription, and with a picture of greater or lesser quality depending on the technology behind the screen. But now consumers are being presented with devices that offer new ways to find, view, and interact with content on their televisions—devices backed by companies with radically different models of what a TV ought to do *(see "Searching for the Future of Television," p. 32).*

The early years of television broadcasting were marked by similar uncertainty. Donald G. Fink, an early authority on TV engineering, who would later become director of research at Philco, described in a January 1941 report for *TR* how the development of commercial television had been stopped dead.

It was on Easter morning, 1940, that the radio industry woke to find on the front pages of the newspapers the startling announcement that the Federal Communications Commission had decided to withdraw its promise of early commercialization of television broadcasting. The reason given by the F.C.C. was that commercial activity in marketing television receivers was in effect establishing a set of television-transmission standards to which the government had not given assent …

With no official standards in place, the industry was preparing to launch commercial television using whatever standards it desired. The industry was in agreement on most of the standards advocated by the Radio Manufacturers Association; hence these were the logical choice. But then the government realized that simply putting receivers designed for these standards into the hands of the public was, in effect, making the standards official.

Action followed swiftly on this realization. The public was warned against buying receivers, and the industry was publicly chastised for usurpation of a government function.

This turn of events smothered the fledgling market for television. Consumers didn't want to buy an expensive new device with such an uncertain future.

It is doubtful that the lay reader realized what was behind the stories. Rather, he became confused, sure only that he would put off buying a television receiver until the government and the industry had composed their differences. Sales of television receivers fell almost to the vanishing point. … The owners of television receivers in New York, variously estimated at between 2,000 and 3,000 in number, found the quality and the frequency of programs declining.

People today know the risks and rewards of being an early adopter, and they're familiar with the idea that a device they buy now might be obsolete in a few years. But in the 1930s and 1940s, the FCC espoused the principle that any radios or TVs sold to the public should retain their "original degree of usefulness" indefinitely, which led the government to delay the launch of commercial television until the members of the newly established National Television System Committee agreed on basic standards.

That committee, composed of industry, academic, and government engineers, dealt with mostly technical issues, like how wide the broadcast frequency band for each channel should be, and how many frames of video should be broadcast per second. But all the issues centered on what the infant technology could do and, more important, what the audience would want it to do. Would it be better to sacrifice a clear picture for less flickering in the broadcast? Should allowances be made for color television? The fundamental task of the committee was to ensure that decisions informed by the limitations of current technology did not inhibit better versions down the line.

As manufacturers introduce interactive TV technology on a large scale, they face a similar challenge. They must avoid changing the viewing experience more than today's audience will tolerate, but they must also make sure not to delay a future in which the distinction between TV and Web content no longer exists. tr

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